Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2004/055

Document de recherche 2004/055

Not to be cited without
Permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: Stock Assessment for 2003 and Advice to Managers for 2004

La morue charbonnière (*Anoplopoma fimbria)* en Colombie-Britannique (Canada) : évaluation du stock en 2003 et avis aux gestionnaires pour 2004

V. Haist[1]
A.R. Kronlund[2]
M.R. Wyeth[2]

[1] Canadian Sablefish Association
406-535 Howe Street
Vancouver, BC V6C 2Z4

[2] Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1499-3848 (Printed / Imprimé)

Canada

Table of Contents

LIST OF TABLES II
LIST OF FIGURES II
ABSTRACT III
RÉSUMÉ IV
1 INTRODUCTION 1
2 STOCK INDICES 2
3 STOCK INDICATORS 4
4 BIOMASS DYNAMICS MODEL AND PERFORMANCE MEASURES 5
5 STOCK STATUS 7
6 ADVICE TO FISHERY MANAGERS 8
ACKNOWLEDGEMENTS 9
LITERATURE CITED 10

APPENDIX A REQUEST FOR WORKING PAPER A-1
APPENDIX B OVERVIEW OF DATA SOURCES B-1
APPENDIX C MANAGEMENT HISTORY C-1
APPENDIX D STOCK ASSESSMENT HISTORY D-1
APPENDIX E COMMERCIAL FISHERY DATA E-1
APPENDIX F ANALYSIS OF COMMERCIAL CATCH RATES F-1
APPENDIX G TAGGING DATA G-1
APPENDIX H ANALYSIS OF TAG RECOVERY DATA H-1
APPENDIX I STANDARDIZED SURVEY DATA I-1
APPENDIX J ANALYSIS OF STANDARDIZED SURVEY DATA J-1
APPENDIX K BIOMASS DYNAMICS MODEL K-1
APPENDIX L SABLEFISH IN NON-DIRECTED SURVEYS L-1
APPENDIX M STATUS OF SABLEFISH IN U.S. WATERS M-1
APPENDIX N ANALYSIS OF THE 2001 ESCAPE-RING STUDY DATA N-1
ERRATUM O-1

List of Tables

TABLE 1 LIST OF APPENDICES AND DESCRIPTION OF CONTENTS. 12
TABLE 2 DECISION TABLES SHOWING THE VALUES FOR FOUR PERFORMANCE MEASURES FOR PROJECTIONS AT A RANGE OF FUTURE CATCH LEVELS. RESULTS ARE PRESENTED RELATIVE TO CURRENT (2003) VULNERABLE BIOMASS, AND THE "EXPECTATION" INTEGRATES OVER THE RANGE OF CURRENT BIOMASS LEVELS.. 13

List of Figures

FIGURE 1 STANDARDIZED COMMERCIAL TRAP FISHERY CATCH RATE INDEX AND STANDARDIZED SURVEY INDEX BY YEAR AND STOCK AREA AREAS. THE VERTICAL DASHED LINE MARKS THE INCEPTION OF ESCAPE RINGS IN THE SABLEFISH TRAP FISHERY. 14
FIGURE 2 COAST WIDE STOCK INDICES: (A) NOMINAL TRAP FISHERY CATCH RATES (SOLID LINE) AND STANDARDIZED TRAP FISHERY INDEX (FILLED CIRCLES), (B) STANDARDIZED SURVEY INDEX ABUNDANCE, AND (C) TAGGING MODEL MARGINAL POSTERIOR DISTRIBUTIONS OF TRAP VULNERABLE BIOMASS. THE DASHED VERTICAL LINE IN PANEL (A) INDICATES THE INCEPTION OF TRAP ESCAPE RINGS. 15
FIGURE 3 QUANTILE PLOTS OF THE MARGINAL POSTERIOR DISTRIBUTIONS OF (A) TRAP VULNERABLE BIOMASS (UPPER PANEL) AND (B) STOCK PRODUCTION (LOWER PANEL). THE MEDIAN IS SHOWN BY HEAVY HORIZONTAL LINES, THE INTER-QUARTILE RANGE BY THE SHADED BOXES, AND THE 5^{TH} AND 95^{TH} PERCENTILES BY THE WHISKERS. 16

Abstract

Sablefish (*Anoplopoma fimbria*) stock status in British Columbia for 2003 was assessed and advice to managers provided for the 2004/2005 fishing year. Four stock abundance indices were evaluated, including (1) standardized survey catch rates, (2) trap vulnerable biomass estimates derived from tag recovery data, (3) standardized commercial catch rates based on fisher logbooks, and (4) nominal catch rates based on commercial trap fishing logbooks and landings. A biomass dynamics model was used to integrate the stock indices and allowed estimation of annual production parameters, where the production terms represent the net changes in biomass resulting from fish growth, recruitment, immigration, emigration, and changes in trap vulnerability. Performance measures were presented in decision tables to allow stock status at different future catch levels to be compared. The performance measures adopted in this assessment were related to biomass levels that should be avoided to ensure conservation concerns for sablefish do not arise.

There was substantial improvement in the standardized survey and commercial catch rates indices in 2003, following the modest improvement observed in 2002. General agreement among the time series of indices indicated that sablefish vulnerable to trap gear experienced a decrease in abundance from higher levels in the early 1990s to low levels in the mid 1990s. The rate of decline slowed in the mid 1990s in both the north and south stock areas. For the north stock area, a period of relative stability occurred in the mid 1990s until 2001 when historically low commercial CPUE and standardized survey results were observed. Standardized survey catch rates in the north increased modestly in 2002 and then improved substantially in 2003. The decline in commercial trap and survey indices for the south stock area was more gradual through the mid 1990s and continued through 2002. However, significant improvement of the 2003 survey index for the south stock area was observed. An increase in the northern standardized commercial catch rates was in agreement with the upturn seen in the standardized survey results. The pattern of tagging model estimates of trap vulnerable biomass was generally consistent with the trends indicated by the commercial catch rates and standardized survey series through 2002.

Production model outputs suggested there was little risk that the TAC levels investigated will lead to a short-term conservation concern for sablefish. However, the model projections are strongly influenced by the substantial increase observed in the 2003 standardized survey and northern trap fishery indices relative to results in 2002. It is not known whether the stock index results in 2003 signal the beginning of period of sustained higher abundance for the B.C. sablefish stock. Support for a sustained period of (relatively) higher sablefish production, and potentially higher TACs, will be drawn from the accumulation of high stock index values over several years.

Résumé

L'état du stock de morue charbonnière (*Anoplopoma fimbria*) en Colombie-Britannique en 2003 a été évalué et des avis pour la saison de pêche 2004-2005 ont été présentés aux gestionnaires. Quatre indices d'abondance du stock ont été calculés, soit (1) les taux de capture pour des relevés normalisés, (2) la biomasse capturable au casier estimée à partir de données de marquage-recapture, (3) les taux de capture normalisés de la pêche commerciale selon les registres de pêche et (4) les taux nominaux de capture au casier selon les débarquements et les registres de pêche commerciale. Un modèle de la dynamique de la biomasse a servi à intégrer les indices et à estimer les paramètres de production annuelle, qui représentent les changements nets dans la biomasse résultant de la croissance, du recrutement, de l'immigration et de l'émigration des poissons, ainsi que des changements dans leur capturabilité au casier. Des mesures de performance sont présentées dans des tables de décision pour permettre la comparaison des états futurs du stock pour différents niveaux de capture. Les mesures de performance utilisés pour cette évaluation sont liés aux niveaux de biomasse qu'il faut éviter pour assurer la conservation de la morue charbonnière.

Les taux de capture de la pêche commerciale et du relevé normalisé se sont considérablement améliorés en 2003, après la légère amélioration observée en 2002. La concordance générale entre les séries chronologiques des divers indices indique que l'abondance des morues charbonnières capturables au casier est passée de valeurs élevées au début des années 1990 à de basses valeurs au milieu des années 1990. Le taux de déclin a ralenti au milieu des années 1990 dans les zones nord et sud du stock. La zone nord a connu une période de stabilité relative du milieu des années 1990 jusqu'en 2001, année où les valeurs de CPUE de la pêche commerciale et les résultats du relevé normalisés étaient faibles. Dans la zone nord, les taux de capture du relevé normalisé ont augmenté légèrement en 2002 et considérablement en 2003. Dans la zone sud, le déclin des indices de pêche commerciale au casier et des indices de relevé a été plus graduel dans le milieu des années 1990 et s'est poursuivi jusqu'en 2002. Toutefois, en 2003 l'indice de relevé pour la zone sud s'est considérablement amélioré. Dans la zone nord, la hausse des taux de capture normalisés de la pêche commerciale correspondait à l'augmentation observée dans les résultats du relevé normalisé. En général, l'évolution de la biomasse capturable au casier estimée au moyen du modèle de marquage-recapture concordait avec les tendances des taux de capture de la pêche commerciale et du relevé normalisé jusqu'en 2002.

Les résultats du modèle de production portent à croire qu'il y a peu de risque que les niveaux de TAC étudiés menaceront la conservation à court terme de la morue charbonnière. Toutefois, la hausse considérable des indices obtenus dans le cadre du relevé normalisé et de la pêche au casier dans la zone nord en 2003 (par rapport à 2002) a un effet important sur les projections du modèle. On ignore si les indices obtenus pour 2003 marquent le début d'une période d'abondance accrue soutenue de la morue charbonnière en C.-B. L'accumulation d'indices de stock élevés sur plusieurs années permettra de conclure à une période soutenue de (relativement) forte production de la morue charbonnière, et de TAC potentiellement plus élevés.

1 Introduction

This document provides an assessment of offshore sablefish (*Anoplopoma fimbria*) stock status in British Columbia for 2003 and advice to fishery managers for 2004. The assessment of sablefish stock status in recent years has depended upon the interpretation of three stock abundance indices: (1) annual estimates of vulnerable biomass derived from a tag-recovery model that utilized tag returns in the first year after release, (2) standardized catch rates obtained from a fishery-independent survey, and (3) commercial catch rates derived from sablefish trap fishery logbooks (Haist and Hilborn 2000, Haist et al. 2001, Kronlund et al. 2002, Kronlund et al. 2003).

In the most recent assessment (Kronlund et al. 2003), a simple biomass dynamics model was used to integrate the stock indices and to provide a pragmatic tool for projecting abundance and identifying choices of total annual catch. Positive results from the 2002 standardized survey had eased concerns about continuing stock decline and evidence from other stock indicators suggested a future increase in sablefish production over the low levels experienced during the 1996 to 2002 period (Kronlund et al. 2003). A perspective paper tabled by the fishing industry (Fargo 2003) reported information based on fishing experience in late 2002 and early 2003. This information suggested increased availability of sablefish particularly in northern B.C. Given the stock was at a low level (Kronlund et al. 2003), fishery performance measures were cast in the context of stock increase. Results from the biomass dynamics model were used to construct decision tables that summarized the probability of achieving the performance measures at various levels of total annual catch (TAC) for three levels of assumed future production.

There are two reasons why stock reconstructions based on population dynamics models are not used for B.C. sablefish assessments. First, available data suggest that sablefish in B.C. do not comprise a closed population. Thus, previous attempts to model tagging data lead to problems in explaining movement of tagged fish and any stock reconstructions were subject to potential bias. Second, sablefish ages are not available after 1996 so that age-structured population models cannot be applied to recent data. Sablefish were last assessed using an age-structured population dynamics model that integrated tag recovery information by Haist and Hilborn (2000).

This assessment is focused on the offshore component of B.C. sablefish, although indicators from data collected in Hecate Strait and Queen Charlotte Sound are reviewed. Sablefish at seamounts and those located in coastal inlets, Hecate Strait, and Queen Charlotte Sound are not considered to be part of the offshore stock. Stock abundance indices similar to those used previously are evaluated, including:

1. 1990 to 2003 standardized survey catch rates;
2. 1991 to 2002 trap vulnerable biomass estimates derived from tag recovery data;
3. 1990 to 2003 standardized commercial catch rates based on trap fishing logbooks;

4. 1979 to 2002 nominal catch rates based on commercial trap fishing logbooks and landings.

The Bayesian biomass dynamics model presented in Kronlund et al. (2003) is modified to incorporate the four indices and now estimates annual production terms. A new tag recovery model that accommodates seasonal immigration and emigration of fish from B.C. waters is introduced and used to generate an index of trap vulnerable biomass. In contrast to recent tagging data analyses, the new model utilizes tag recoveries regardless of the number of years at large and is cast in a Bayesian framework to allow the assessment of uncertainty. Ancillary indicators that bear on sablefish stock status in British Columbia are considered, including the occurrence of sablefish in the International Pacific Halibut Commission standardized survey, B.C. shrimp surveys, and a deep-water longspine thornyhead (*Sebastolobus altivelis*) survey. The results of sablefish stock assessments conducted in Alaska and the continental United States (U.S.) are briefly reviewed, and an analysis of new sablefish trap escape-ring data is provided.

Objectives for this assessment identified in a PSARC Request for Working Paper (Appendix A) include:

1. To review surveys, biological sampling, catch records, logbooks, observer reports, tag-recovery and fishing practices for sablefish to provide a basis for management for the 2004/2005 fishery;
2. To provide an assessment of sablefish stock status;
3. To present various fishery performance measures and a decision table with appropriate yield options.

This document consists of a main document with supporting Appendices A through N that can be consulted for more detailed information, as required (Table 1). Tables and figures referred to in the main text are sequentially numbered. Tables and figures in appendices are labeled with the letter code of the appendix and a sequential number, e.g., Table B.2 for the second table in Appendix B. Equations presented in the main text are numbered sequentially, as are equations within each appendix.

2 Stock Indices

Four stock indices are utilized in this assessment. Two indices are based on commercial trap fishery catch rates (CPUE) derived from logbook and landings data and a third one on trap catch rates derived from a fishery-independent standardized survey (Figure 1, Figure 2). The fourth index consists of annual estimates of trap vulnerable biomass derived from a tagging model (Figure 2). The stock indices are described below.

Nominal trap catch rates (1979-2002, Appendix E). Recent coast-wide catch rates (kg/trap) are at, or slightly below, levels experienced in the early 1980s. This time series is not standardized and coincides with a period of change in the fishery management regime and fishing practices (Appendix C). The timing of the peak of nominal trap

CPUE during the early 1990s is consistent with a similar pattern observed for the Gulf of Alaska stock (Appendix M), though the timing is lagged in B.C. relative to Alaska. Catch rate data from 2003 are not included because there was no trap fishing after March 2003 until after the August 1, 2004 start of the new fishing year. Thus, the estimate of nominal CPUE for 2003 is not comparable in terms of seasonal coverage to previous estimates.

Standardized commercial trap catch rates (1990-2003, Appendix F). Trap fishery catch rates (kg/trap) for the north coastal area declined from 1991 to 1998 prior to the mandatory adoption of escape rings in the trap fishery (Figure 1). Subsequent to 1998 the four-year trend indicates a decline, with a low in 2001 and improvement in 2002 in agreement with the standardized survey trajectory. The index increased substantially (63 percent) in 2003 over the level observed in 2002 and is the highest value in the period after the adoption of escape-rings in traps. The south coastal area catch rates initially increased and then declined from 1992 through 1998 (Figure 1). Subsequent to 1998, the four-year trend is relatively flat. There was no south coast trap fishing in the first half of 2003, so it was not possible to estimate a standardized index value. The coast wide standardized abundance index reflects the composite of the north and south trends, and the increase in 2003 due to improved catch rates in the north (Figure 2).

Standardized trap survey (1990-2003, Appendix J). Coast wide results from the standardized trap survey show substantially increased catch rates (mean number per trap) in 2003 and reflect results in both the north and south stock areas (Figure 2, Appendices I, J). The historical trend for both north and south stock areas shows a general decline in catch rates from highs in the early 1990s (Figure 1). Beginning in the mid-1990s, the rate of decline generally decreased, and there was a period of relative stability through to 2000. The 2001 survey produced the lowest mean and median catch rates observed in the times series, with marked reduction of the variance for the north stock area in particular. Catch rates for the north stock area improved in 2002 relative to 2001, and were comparable to those observed in the mid-1990s, but with higher variability. Catch rates in 2003 increased substantially to a historical high, with similarly high variability among sets for the north stock area. Catch rates in the south stock area exhibit a continuous decline from the mid-1990s to 2002, but show significant increases in 2003 largely due to improved catches in three shallower depth strata. Catch rates in 2003 were similar to those observed in 1992. Catch rates at the Barkley Canyon survey locality did not show general improvement over the low level observed in 2002.

Tagging model estimates of trap vulnerable biomass (1991-2002, Appendix H). Trap vulnerable biomass estimated by the tagging model declined from a high in 1993 through 1998. The estimated biomass remained at low levels from 1998 through 2002, with a historical low in 2001 in agreement with the standardized survey and commercial catch rates. Trap vulnerable 2003 biomass was not estimated using the tagging model because trap fishery tag recoveries were available only for the first two months of 2003 and limited to the north coastal area. Attempts to fit these data would have a high risk of biased estimates.

3 Stock Indicators

Stock indicators analyzed in this assessment are summarized below. The indicators include results of neighboring stock assessments in Alaska and the continental U.S., and the results of directed surveys where sablefish occur as bycatch. The survey data were analyzed as part of ongoing evaluation of their potential to provide information on sablefish stock status.

Gulf of Alaska sablefish stock status (Appendix M). Abundance is now considered to be at a moderate level with the 1997 year class projected to comprise 31 percent of the 2004 spawning biomass. Relative abundance in 2003 is 10 percent higher than in 2000. The 1998 year class may be above average, though it is not expected to be as strong as the 1997 year class. Juvenile surveys indicated that the 1997 and 1998 year classes would be above average, but to date the 1998 year class appears relatively weak in stock assessment model estimates (Sigler et al. 2003). Projected 2004 spawning biomass is 40 percent of unfished biomass, but is projected to fall to 33 percent by 2007 under the maximum permissible yield specified by the U.S. adjusted $F_{40\%}$ harvest policy. A long term decline in the East Yakutat/Southeast area was noted as a serious concern to U.S. biologists, since that area is considered part of the core spawning region. However, the recommended 2004 yield for the area was not reduced from the 2003 level.

Continental U.S. indicators (Appendix M). Relatively strong 1999 and 2000 year classes were observed by the triennial shelf survey, and the 2001 shelf survey results are the highest in the 1980 to 2001 series (Schirripa 2002). These signs that the 1999 and 2000 year class might be very good in the waters off the continental U.S. follows poor recruitment through the 1990s (Schirripa and Methot 2001, King et al. 2001) and a concurrent decline in sablefish spawning stock biomass off the continental U.S. over the same period.

Longspine thornyhead survey (2001-2003, Appendix L). The estimated biomass of sablefish off the west coast of Vancouver Island, based on data collected during a fall thornyhead survey, suggested a decline from 2001 to 2002 followed by an increase in 2003 to the 2001 level. Estimated sablefish abundance during the 2003 survey was highest in the shallow stratum (500-800 m) and lowest in the deep stratum (1200-1600 m).

West Coast Vancouver Island Shrimp Survey (1979-2003, Appendix L). The west coast Vancouver Island shrimp survey, conducted at shallow depths (50 to 200 m) in management areas 124 and 125, intercepts juvenile sablefish. Sablefish catch rates increased markedly in 2001 and 2002, and subsequently declined in 2003. These results are in agreement with sablefish catch rates from the continental U.S. shelf and slope surveys and bycatch rates in the U.S. Pacific hake (*Merluccius productus*) fishery (Schirripa 2002), where the 1999 and 2000 year classes appeared to be above average.

IPHC Standardized Survey catch rates (1993-2003, Appendix L). Mean catch rates peaked in 1998 in the Hecate Strait and Queen Charlotte Sound area. Mean catch rate in

2003 was similar to the 2002 estimate for this area. It is not clear whether the 1998 peak was the result of an above average 1997 year class, given size frequency data are only available for 2003 and few fish below 45 cm were selected by the gear in 2003. Two year old fish in B.C. are about 40 cm while 3 to 4 year old fish are about 45 to 50 cm. A similar pattern in mean catch rates was observed off the northern Queen Charlotte Islands. The time series of data for the west coast of Vancouver Island is not extensive (1999, 2001-2003), but the highest catch rates observed in 2001 were about twice those observed in other years. Again, no biological data were available prior to 2003 to characterize the fish.

4 Biomass Dynamics Model and Performance Measures

The biomass dynamics model introduced in 2003 (Kronlund et al. 2003) was extended to estimate annual production parameters (Appendix K). This change allowed inter-annual variation in stock production to be modeled, where the production terms represent the net changes in biomass resulting from fish growth, recruitment, immigration, emigration, and changes in trap vulnerability. Nominal commercial trap fishery catch rates (CPUE) were introduced as a stock index, so that a total of four stock indices (Figure 2) and annual catch data were input to the biomass dynamics model. The inclusion of nominal CPUE extended the time series of data back to 1979 and thereby encompassed a period of contrast in a stock index which was assumed to reflect relatively higher biomass in the late 1980s and early 1990s. Note that all four stock indices relate to trap vulnerable biomass, and do not index sablefish in B.C. waters such as those at seamounts, Hecate Strait, Queen Charlotte Sound or coastal inlets. Furthermore, sablefish distributed shallower (or deeper) than those vulnerable to the commercial, survey, and tagging effort would not be indexed.

A Bayesian approach, based on the Markov Chain Monte Carlo (MCMC) algorithm (Gelman et al. 1995), was used to estimate the joint posterior distribution of model parameters. Distributions of the trap vulnerable biomass estimates and of the stock production estimates are shown as Figure 3. These distributions suggested there were possible production stanzas demarcated by 1994. This division was used to define "good", 1980 to 1993, and "poor", 1994 to 2002, production stanzas. The biomass dynamics model was used to project trap vulnerable stock biomass and production trends over the 2004 to 2008 period for a range of potential future catch levels. Each simulation held the annual catch fixed over the projection period. Long term (1000 year) simulations were conducted for no-catch scenarios to provide estimates of the distribution of unfished trap vulnerable biomass. The long-term simulations suggested that if switching between equal-length periods of good and poor production occurred, the biomass would fall below 19,000 t about 5 percent of the time. Since this level of biomass would be expected to occur 1 in every 20 years even in the absence of fishing, it was considered a level that should not lead to conservation concerns. Thus, two performance measures based on the 5th percentile of the distribution of unfished trap vulnerable biomass, $B^{0.05}$=19,000 mt were adopted.

In the previous assessment (Kronlund et al. 2003), the performance measures were related to stock increase because the stock indices were at, or near, the lowest level observed in the available time series. The substantial improvement in the 2003 standardized survey and northern B.C. trap fishery indices, and therefore the relatively high estimates of trap vulnerable biomass for 2003, means that performance measures based on increasing the stock biomass are not useful. However, assessing whether future stock biomass remains above the 2002 estimates of vulnerable biomass was used as a basis to define two additional performance measures.

The performance measures adopted for this assessment relate to the trap vulnerable biomass in 2002 (B_{2002}) and the 5th percentile of the unfished trap vulnerable biomass ($B^{0.05}$, estimated at 19,000 t):

1. The *probability* that vulnerable stock biomass is above $B^{0.05}$ at the end of the projection period, $P\left(B_{2009} > B^{0.05}\right)$;
2. The *probability* that vulnerable stock biomass is above B_{2002} at the end of the projection period, $P\left(B_{2009} > B_{2002}\right)$;
3. The *magnitude* of the expected change in vulnerable stock biomass over the projection period, $E\left(B_{2009} / B^{0.05}\right)$;
4. The *magnitude* of the expected change in vulnerable stock biomass over the projection period, $E\left(B_{2009} / B_{2002}\right)$.

Performance measures were summarized as decision tables that allowed stock status at different future catch levels to be compared (Table 2). The biomass dynamics model constructed the marginal distribution of B_{2003} over the sample from the MCMC chain. Then, the distribution of B_{2003} values was used in decision tables to summarize results relative to current stock condition, i.e., the impacts of the B_{2003} being at the lower (or higher) end of the range of estimated values. This was achieved by dividing the marginal posterior distribution of 2003 vulnerable biomass estimates into three ranked groups using the 0th-25th, 25th-75th, and 75th-100th quantiles. Performance measures were presented for each of these groups to represent expected outcomes given poor, medium, or good levels of biomass in 2003. Note that the group differences are relative.

The performance measures adopted in this assessment are related to biomass levels that should be avoided to ensure conservation concerns for sablefish do not arise. A specific harvest policy (e.g., a fixed fishing mortality rate) is not recommended for B.C. sablefish at this time for two reasons. First, the annual, seasonal, and spatial patterns in catch rates (Appendix E) and the evidence from tagging analyses (Beamish and McFarlane 1983, 1988, Kimura et al. 1998, Kronlund et al. 2003, Appendix H) provided strong evidence that B.C. sablefish do not comprise a closed population. Commercial fishery catch rates show high values in the December to March period in northern B.C., which tended to move in a southerly direction through the year. Tags recovered per tonne of sablefish landed tended to decrease in the December to March period, suggesting an influx of untagged fish into the tagged population which subsequently become unavailable to the fishery through removals or movement to non-vulnerable areas. Given the longevity of sablefish, large changes that have occurred in the stock indices (e.g., 1993 to 1994, 2000 to 2001, 2002 to 2003 changes in standardized survey index values) cannot be explained using standard population dynamics such as recruitment and fishing mortality. The abundance of sablefish in the trap vulnerable component of the B.C. stock appears to be related in part to the amount of fish movement. Thus, attempts to model a B.C. spawning biomass and calculate biological reference points are problematic because the closed population assumption is not met. An open population assumption is explicit in the structure of both the tagging model (Appendix H) and the biomass dynamics model (Appendix K); the latter is not formulated using a standard surplus production approach. The fishery performance measures selected for this analysis are consistent with the model assumptions, but other measures are possible and will lead to different choices of yield. Second, the absence of fishery objectives means that there is no basis for evaluating alternative harvest policies.

5 Stock Status

There was substantial improvement in the standardized survey and commercial catch rates indices in 2003 relative to values observed during the late 1990s through 2002. This increase followed a modest improvement observed in 2002. General agreement among the time series of indices indicated that sablefish vulnerable to trap gear experienced a decrease in abundance from (relatively) high levels in the early 1990s to low levels in the mid 1990s. The rate of decline slowed in the mid-1990s for both stock areas. For the north stock area, a period of relative stability occurred in the mid 1990s until 2001 when historically low commercial CPUE, standardized survey, and tagging results were observed. Standardized survey catch rates in the north increased in 2002 and then improved substantially in 2003. Significant improvement in the 2003 survey index for the south stock area was also observed. The decline in commercial trap and survey indices for the south stock area was more gradual through the mid 1990s and continued through 2002. An increase in the northern standardized commercial catch rates is in agreement with the upturn seen in the standardized survey results. The pattern of tagging model estimates of trap vulnerable biomass was generally consistent with the trends indicated by the commercial catch rates and standardized survey series through 2002.

All of the stock indices analyzed in this assessment are short time series compared to sablefish longevity (70+ years) and hence long generation time. The indices also relate only to sablefish that are vulnerable to trap gear. With the exception of the nominal catch rate series (1979 to 2002), each series is limited to about 15 years of data that must be judged relative to the long history of sablefish exploitation. Three of the stock indices do not provide an absolute estimate of sablefish abundance and should be viewed as providing a relative index for the component of the sablefish population measured. The tagging model estimates of trap vulnerable biomass are stated in terms of biomass, but are associated with considerable uncertainty, particularly early in the time series. These indices relate to the offshore biomass (excluding seamounts) vulnerable to trap gear and do not, for example, index juvenile sablefish or those residing in the inside waters of Hecate Strait or coastal inlets. It is not known what factors motivate sablefish to enter traps, and hence it is not clear what component of the stock is selected by the gear. Also, the relative proportion of the total sablefish stock indexed by the trap-related indices cannot be estimated using the available data.

Results from indicators such as the west coast Vancouver Island shrimp survey and U.S. triennial shelf and slope surveys suggest production due to contributions from the 1999 and/or 2000 year-classes may materialize in the trap fishery starting about 2005. However, the positive outlook derived from the stock indices is largely dependent on results in 2003 relative to those in 2002, and it is not known whether high catch rates will persist over a period of years as occurred during the late 1980s and early 1990s. There was relatively little trap fishing activity in the months preceding the fall 2003 standardized survey. Fishermen cited the presence of fishing activity immediately preceding the 2001 survey as a possible explanation for the low index point (Kronlund et al. 2002). Conversely, it is not known to what degree the improvement in the 2003 survey index point benefited from a relative absence of trap fishing activity in the months preceding the fall 2003 survey. Variability in seasonal availability of sablefish in the December to March period could significantly affect the stock indices as, for example, in the transition from 2002 to 2003, or that experienced during the recent historic low that occurred in 2001.

6 Advice to Fishery Managers

Based on the stock indices, the model outputs suggest there is little risk that the TAC levels investigated with the biomass dynamics model will lead to a short-term conservation concern. However, the model projection outputs are driven by the substantial increase observed in the 2003 standardized survey and northern trap fishery catch rates relative to values in 2002. It is not known whether the stock index results in 2003 signal the beginning of period of sustained higher abundance for the B.C. sablefish stock. Support for a sustained period of (relatively) higher sablefish production, and potentially higher TACs, will be drawn from the accumulation of high stock index values over several years.

Since 1980, annual sablefish landings have averaged 4,300 mt and about 5,100 mt during the 1988 to 1993 period. The latter period experienced sustained higher stock index values for about 5 to 7 years as measured by the nominal and standardized commercial catch rates. The standardized survey initiated in 1990, and the tagging program initiated in 1991, suggested a decline in abundance from higher levels from the early to the mid 1990s. The average landings were about 4,000 mt from 1994 to 2002, which was maintained during a period of gradual decline in the stock indices until 2000. The substantial improvement in stock indices observed in 2003 is cause for optimism, but there is no means of predicting whether indices will remain high or whether the commercial fishery and tagging indices will be in agreement with 2003 results as a more typical fishing pattern is restored.

Selection of yield may be assisted by use of the decision tables and by inspection of the landings history. Ideally, yield choices would be resolved in the context of fishery objectives which typically involve trade-offs between stability of annual catches and exploiting opportunities for higher, but more variable, annual catches. For example, the selection of a high yield in one year will increase the probability that a reduction will be required in the subsequent year. Fishery objectives also involve integrating considerations across more than one gear sector, as may be the case for the directed sablefish trap and longline fleets, and the trawl fleet. Although work on sablefish fishery objectives initiated in 2003 will in the long-term provide a formal framework for decision making, in the short-term *ad hoc* consideration of trade-offs between yield and stability of catch is required.

We note that the decision procedure used here is not intended to set harvest levels over the duration of the projection period. By necessity, frequent review of the stock indices and indicators will be required pending identification of fishery objectives and development of a satisfactory population dynamics model to examine the long-term harvest strategies. The latter task will require consideration of data from U.S. sources.

Acknowledgements

We are grateful for the careful review provided by Sean Cox. Like most stock assessment documents, this paper reflects the contributions of many individuals. Members of the Canadian Sablefish Association and CSA staff collaborated in the development, implementation and analysis of sablefish stock assessment programs. The longspine thornyhead survey data were provided courtesy of Pacific Biological Station Groundfish staff, Paul Starr and the Canadian Groundfish Research and Conservation Society. The International Pacific Halibut Commission assessment set-line survey data were kindly provided by Bruce Leaman and Claude Dykstra. The shrimp trawl survey data was provided by Jim Boutillier who assisted with interpretation. We appreciate the assistance of Norm Olsen in providing advice for shrimp survey data extraction. Michael Sigler kindly gave permission to include figures from the Gulf of Alaska sablefish stock assessment. We are grateful for the conscientious work of numerous individuals involved in the preparation and processing of data used in this document. In particular, the contributions of Wendy Mitton (Pacific Biological Station) and Margo Elfert (Archipelago Marine Research) are greatly appreciated. Discussions with Paul Starr, Ray Hilborn, Bruce Turris, Brian Mose, Brian Dickens, Eric Wickham, Chris Acheson, Bob Fraumeni, Erling Olsen, Henry Heggelund, Blair Pearl and members of the Canadian Sablefish Association were greatly appreciated.

Literature Cited

Beamish, R.J. and G.A. McFarlane. 1983. Summary of results of the Canadian sablefish tagging program. p. 147-183. *In* Proceedings of the Second Lowell Wakefield Fisheries Symposium. Anchorage, AK. Alaska Sea Grant Report 83-8.

Beamish, R.J. and G.A. McFarlane. 1988. Resident and dispersal behavior of adult sablefish (*Anoplopoma fimbria*) in the slope waters off Canada's west coast. Can. J. Fish. Aquat. Sci. **45**: 152-164.

Fargo, J. 2003. Proceedings of the PSARC Groundfish Subcommittee Meeting, January 14-15, 2003. Can. Sci. Adv. Sec. Proc.Ser. 2003/002.

Gelman, A.B.; Carlin, J.S.; Stern, H.S.; Rubin, D.B. (1995): Bayesian data analysis. Chapman & Hall, London. 526 p.

Haist, V. and R. Hilborn. 2000. Sablefish stock assessment for 2000 and recommended yield options for 2001. Can. Stock. Assess. Sec. Res. Doc. 2000/157. 78 p.

Haist, V., Hilborn, R., and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. Can. Sci. Advisory Res. Doc. 2001/135. 54 p.

Kimura, D.K., Shimade, A.M., and F.R. Shaw. 1998. Stock structure and movements of tagged sablefish, *Anoplopoma fimbria* in offshore northeastern Pacific waters and the effects of El Nino-southern oscillation on migration and growth. Fish. Bull. 96: 462-481.

King, J.R. McFarlane, G.A., and R.J. Beamish. 2000. Decadal-scale patterns in the relative year class success of sablefish (*Anoplopoma fimbria*). Fish. Oceanogr. 98: 62-72.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

Kronlund, A.R., M. Wyeth, and R. Hilborn. 2002. Review of survey, commercial fishery, and tagging data for sablefish (*Anoplopoma fimbria*) in British Columbia: Supplement to the November 2001 sablefish stock assessment. Can. Sci. Adv. Sec. Res. Doc. 2002/074. 109 p.

Sigler, M.F., Lunsford, C.R., J.T. Fujioka and S.A. Lowe. 2003. Alaska sablefish assessment for 2003. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2004. November 2003, Plan Team Draft (http://www.afsc.noaa.gov/refm/stocks/assessments.htm).

Schirripa, M.J. and R. Methot. 2001. Status of the sablefish resource of the U.S. Pacific coast in 2001. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

Schirripa, M.J. 2002. Status of the sablefish resource off the continental U.S. Pacific coast in 2002. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

Table 1 List of appendices and description of contents.

Appendix	Contents
Appendix **A** Request for Working Paper	Request for management advice.
Appendix **B** Overview of Data Sources	Listing of data sources used in this assessment.
Appendix **C** Management History	Review of fishery management including quota history and list of significant management tactics.
Appendix **D** Stock Assessment History	Review of stock assessment history, current impediments to assessment, and steps taken to improve assessment data.
Appendix **E** Commercial Fishery Data	Description of commercial fishery catch and effort data, exploratory analysis of nominal commercial catch rates.
Appendix **F** Analysis of Commercial Catch Rates	Estimation of a standardized commercial catch rate index.
Appendix **G** Tagging Data	Description of tagging programs and data, exploratory graphical analyses of tagging data.
Appendix **H** Analysis of Tag Recovery Data	Description of a new Bayesian tagging model and estimation of a trap vulnerable biomass index.
Appendix **I** Standardized Survey Data	Description of standardized survey program and data.
Appendix **J** Analysis of Standardized Survey Data	Estimation of a standardized survey catch rate index.
Appendix **K** Biomass Dynamics Model	Description of the biomass dynamics model used to integrate stock indices, forward projections, and rationale for performance measures.
Appendix **L** Sablefish in non-directed surveys	Review and analysis of sablefish caught in the IPHC standardized stock assessment survey, shrimp surveys, and deep-water longspine thornyhead survey.
Appendix **M** Status of sablefish in U.S. waters	Summary of the results of the 2003 Alaska sablefish stock assessment and the most recent assessment for the continental U.S.
Appendix **N** Analysis of the 2001 escape-ring study data	Analysis of an escape-ring study that describes impacts on stock assessment.

Table 2 Decision tables showing the values for four performance measures for projections at a range of future catch levels. Results are presented relative to current (2003) vulnerable biomass, and the "expectation" integrates over the range of current biomass levels.

Total Annual Catch 2004-2008	$P(B_{2009} > B_{2002})$			
	Current Biomass			
	Low	Average	High	Expectation
0	0.98	0.95	0.89	0.94
3000	0.95	0.92	0.85	0.91
4000	0.93	0.90	0.83	0.89
5000	0.91	0.88	0.80	0.87
6000	0.87	0.85	0.77	0.83

Total Annual Catch 2004-2008	$P(B_{2009} > B^{0.05})$			
	Current Biomass			
	Low	Average	High	Expectation
0	0.97	0.98	0.97	0.97
3000	0.94	0.95	0.96	0.95
4000	0.93	0.93	0.94	0.93
5000	0.90	0.92	0.93	0.92
6000	0.87	0.89	0.91	0.89

Total Annual Catch 2004-2008	$E\left(B_{2009} / B_{2002}\right)$			
	Current Biomass			
	Low	Average	High	Expectation
0	3.35	2.81	2.33	2.83
3000	3.03	2.56	2.14	2.57
4000	2.91	2.47	2.06	2.48
5000	2.77	2.37	1.99	2.37
6000	2.62	2.26	1.90	2.26

Total Annual Catch 2004-2008	$E\left(B_{2009} / B^{0.05}\right)$			
	Current Biomass			
	Low	Average	High	Expectation
0	2.96	3.08	3.15	3.07
3000	2.68	2.81	2.89	2.80
4000	2.57	2.71	2.80	2.70
5000	2.45	2.60	2.69	2.59
6000	2.32	2.47	2.58	2.46

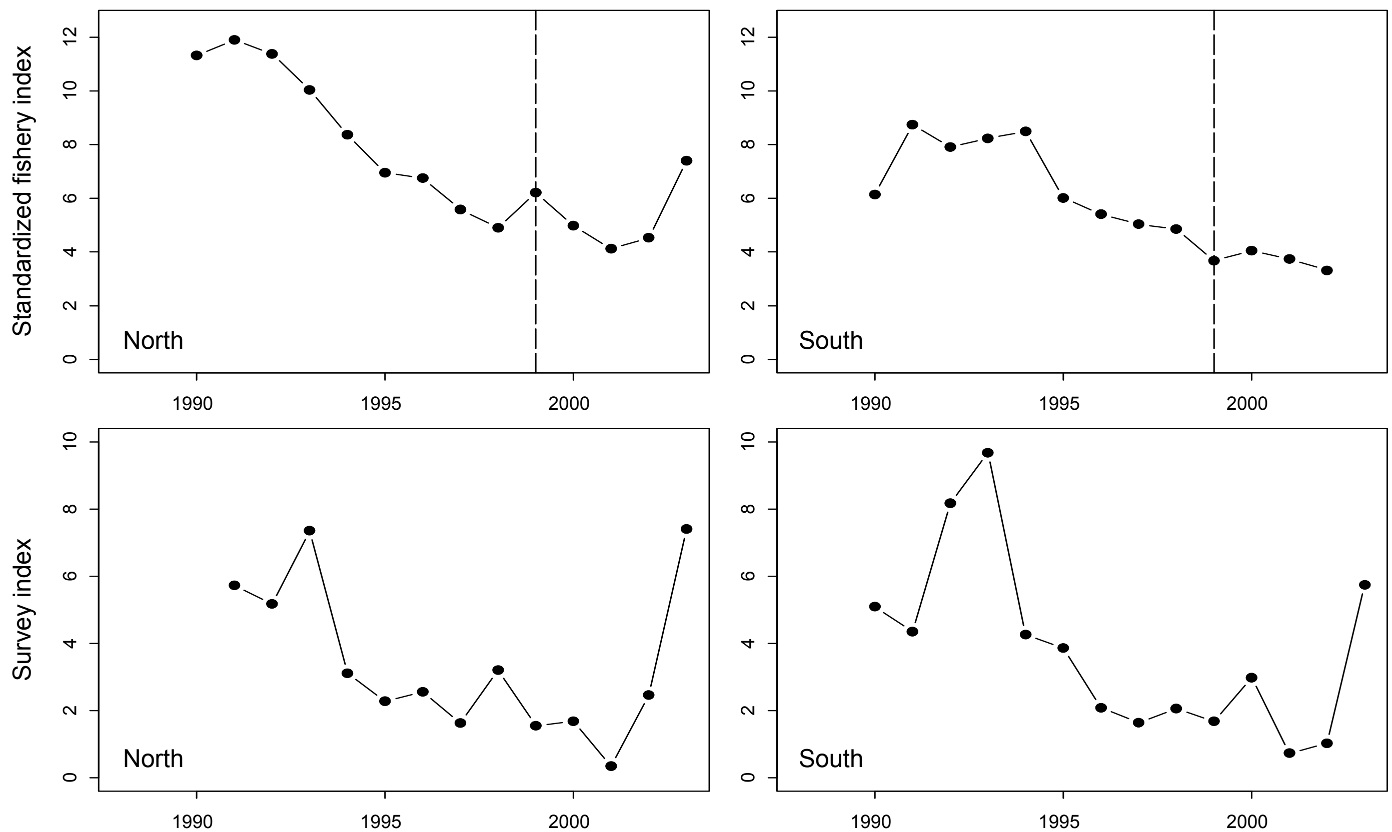


Figure 1 Standardized commercial trap fishery catch rate index and standardized survey index by year and stock area areas. The vertical dashed line marks the inception of escape rings in the sablefish trap fishery.

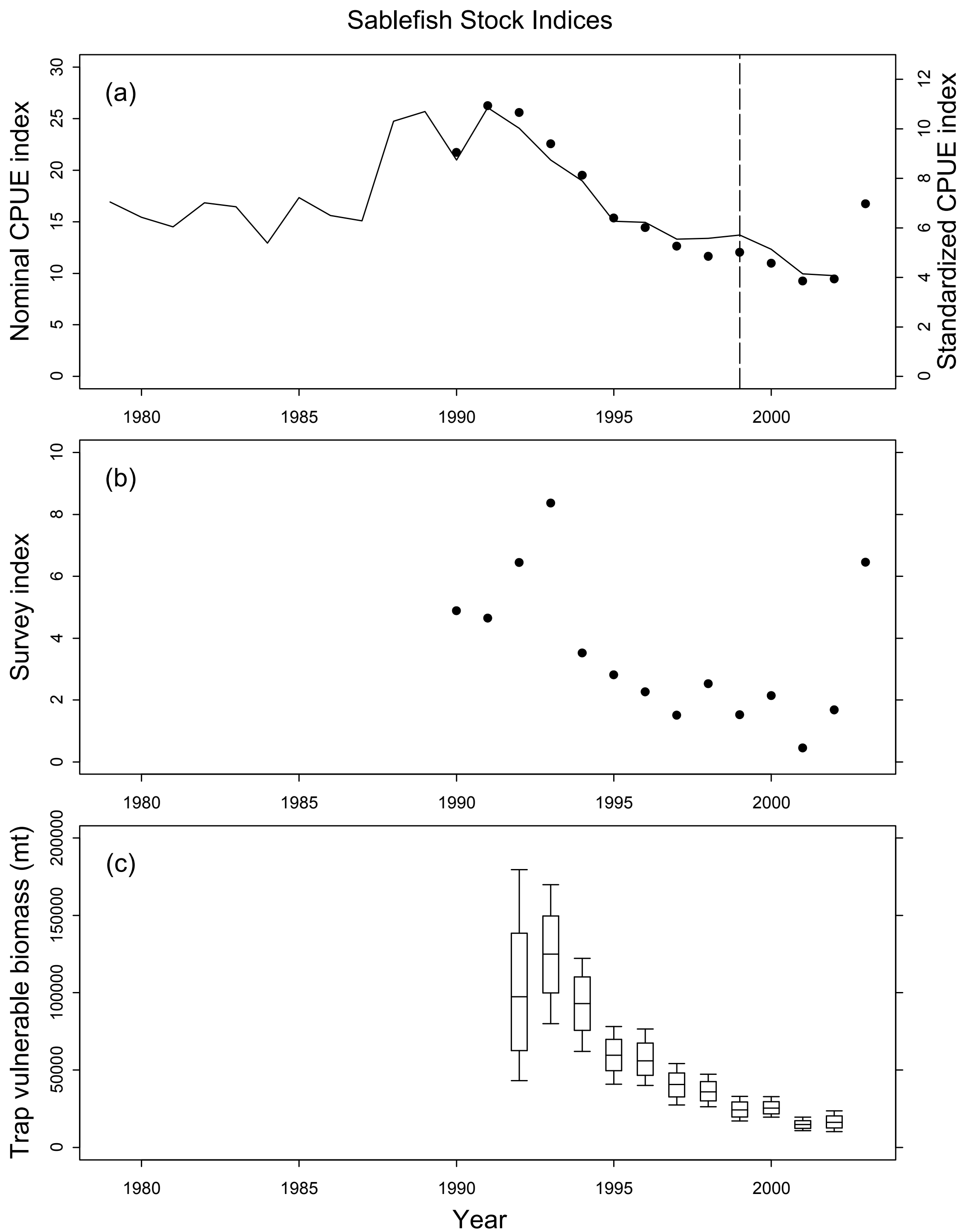


Figure 2 Coast wide stock indices: (a) nominal trap fishery catch rates (solid line) and standardized trap fishery index (filled circles), (b) standardized survey index abundance, and (c) tagging model marginal posterior distributions of trap vulnerable biomass. The dashed vertical line in panel (a) indicates the inception of trap escape rings.

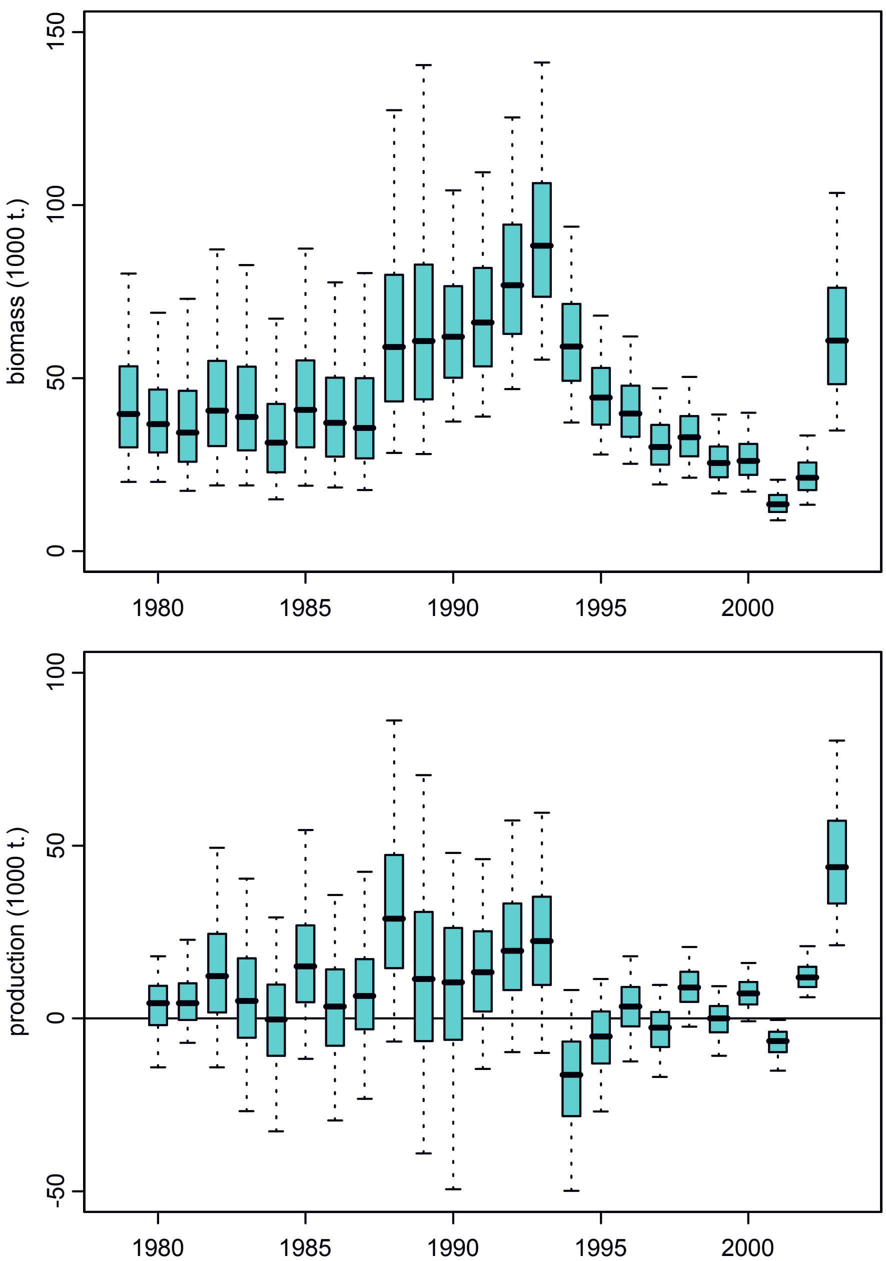


Figure 3 Quantile plots of the marginal posterior distributions of (a) trap vulnerable biomass (upper panel) and (b) stock production (lower panel). The median is shown by heavy horizontal lines, the inter-quartile range by the shaded boxes, and the 5^{th} and 95^{th} percentiles by the whiskers.

APPENDIX A PSARC REQUEST FOR WORKING PAPER

Date Submitted: November 27, 2003

Individual or group requesting advice: Groundfish Management Unit

Proposed PSARC Presentation Date: January 21, 2004

Subject of Paper (title if developed):

Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: Stock Assessment for 2003 and Advice to Managers for 2004

Stock Assessment Lead Author: V. Haist **Coauthors**: A.R. Kronlund, M. Wyeth

Fisheries Management Author/Reviewer: Terri Bonnet/Al MacDonald

Rational for request: An annual assessment is conducted for sablefish and advice is presented in the form of a decision table for Canadian harvests (commercial, First Nations, recreational, experimental).

Question(s) to be addressed in the Working Paper:

1. To review surveys, biological sampling, catch records, logbooks, observer reports, tag-recovery and fishing practices for sablefish to provide a basis for management for the 2004/2005 fishery;
2. To provide an assessment of sablefish stock status;
3. To present various fishery performance measures and a decision table with appropriate yield options.

Stakeholders Affected: Sablefish range is coast-wide and the species is found at various depths. The stakeholders affected include such groups as commercial K & T licence holders, recreational users, processing plants, buyers, and others.

How Advice May Impact the Development of a Fishing Plan: The advice is critical for the development of fishing plans and management decisions.

Timing Issues Related to When Advice is Necessary: Results from this PSARC paper are required so that a TAC can be identified for the start of the commercial trawl fishery on April 1, 2004 and the sablefish fishery on August 1, 2004. It is anticipated that presentation of the paper at the PSARC Groundfish Subcommittee meeting on January 20-21, 2004 will permit the Department to meet its obligations in providing advice to fishery managers.

APPENDIX B OVERVIEW OF DATA SOURCES

A tabular listing of sablefish-related data used for analyses in this assessment is provided in this section. The data type, primary variables, and temporal and spatial coverage are described. A reference to the section or appendix that contains the data selection criteria is provided, and the data source is noted in the table. Some sablefish data may not be included in the list because they are not computer accessible, or may require significant auditing before they can be considered reliable. Other data may not be relevant to the present analyses. Note that information may not be complete for all variables listed. For example, effort may be missing for some logbook records where catch is present, or length and age may be recorded for a given fish but no associated weight or maturity data are available. Ages are not available after 1996, although otoliths have been collected and archived.

Data Type	Response Variables	Associated Variables	Coverage	Selection Criteria	Source
Directed surveys:					
Standardized survey (sablefish trap)	Catch (wt, #) Effort (traps) Species	Survey set Lat/Lon Depth Date/Time	1990-2003 50-1,000 fm Sep-Nov	Appendix I, J	GFBio
Tagging survey (sablefish trap)	Releases Recoveries	Survey set Lat/Lon Depth Date/Time Fishery type Fishery set	1990-2003 50-800 fm Sep-Nov	Appendix G	Tag_Releases. mdb GFBio PacSableTag
Survey biosamples (individual sablefish)	Length Weight Sex Maturity Age (to 1996)	Survey set Location Depth Date/Time Tag number	1990-2003 50-1,000 fm Sep-Nov	Appendix I	GFBio
Non-directed surveys:					
Thornyhead survey (trawl)	Catch (wt) Effort (area swept) Species Lengths	Survey set Lat/Lon Date/Time Depth	2001-2003 Aug-Sep West coast Vancouver Is.	Appendix L	GFBio
IPHC halibut survey (longline)	Catch (#) Effort Species	Survey set Lat/Lon Date/Time Depth	1993-2003 Jun-Jul IPHC area 2B	Appendix L	IPHC SSA database
Shrimp survey (trawl)	Catch (kg) Effort Species	Survey set Lat/Lon Date/Time Depth	1975-2003 < 200 m May-Jun	Appendix L	Shellfish Data Unit GFBio (2003)

Data Type	Response Variables	Associated Variables	Coverage	Selection Criteria	Source
Sablefish K fishery:					
Logbooks (trap and longline)	Catch (*weight for trap, pieces for longline*) Effort	Set no. Lat/Lon Management area Date/Time Depth	Longline: 1987-2003 Trap: 1990-2003 Fishing year Coastwide	Appendix E, F	PacHarvSable
Dockside validated landing	Landing by species	Trip no. Date/Time Management area	1995-2003 Fishing year Coastwide	Appendix E, F	PacHarvSable
Landings (Landings records and logbooks)	Landings by species	Trip no. Date/Time Management area	Longline: 1979-1986 Trap: 1979-1995 Fishing year Coastwide	Appendix E, F	GFCatch
Landings (landings records)	Landings by species	Date	Longline: 1987-1994	Appendix E	PacHarv 3.0
Landings (fishery reports)	Landings	Gear	1913-1981	Appendix E	McFarlane and Beamish (1983)
Fishery biosamples (Individual fish)	Length Weight Sex Age (some)	Trip no. Set Date/Time Vessel	1992-2002 Fishing year Coastwide	Not used in this document.	quota biodata.mdb
Other fisheries:					
Dockside Validated Landings (trawl "T" fishery)	Landings by species	Trip no. Date/Time Management area	1996-2003 Fishing year Coastwide	Appendix E	PacHarvTrawl
Landings (trawl "T" sales slips, logbooks)	Landings by species	Trip no. Date/Time Management area	1954-1995 Fishing year Coastwide	Appendix E	GFCatch
Observer logs (trawl "T" fishery)	Catch (t) Effort Species	Set no. Lat/Lon Date/Time Depth	1996-2003 Fishing year Coastwide	Appendix E	PacHarvTrawl

APPENDIX C MANAGEMENT HISTORY

C.1 DIRECTED SABLEFISH "K" FISHERY C-1
C.2 MANAGEMENT BY TOTAL ALLOWABLE CATCH C-1
C.3 MANAGEMENT BY INDIVIDUAL VESSEL QUOTA C-2
C.4 OVERAGE/UNDERAGE RULES C-3
C.5 OTHER MANAGEMENT TACTICS C-4
C.6 FISHERY MONITORING MEASURES C-5
C.7 LITERATURE CITED C-5

The history of sablefish fishery management is summarized in Table C.1. The table contains a list of the annual total allowable catches (TACs) and quota allocations to the directed sablefish "K" fleet, the non-directed trawl "T" fleet, First Nations, and science projects. A narrative of the management history of sablefish by fishing year is provided in Table C.2. Material in this section was drawn from management plans (see, for example, Fisheries and Oceans Canada 2002, 2003) and unpublished file material from the Groundfish Management Unit, Pacific Region, Fisheries and Oceans Canada.

C.1 Directed sablefish "K" fishery

Fishing under a "K" licence is permitted using trap and/or hook and line gear. A generalised gear description follows. Both methods involve attaching baited gear at intervals along a groundline secured to the ocean floor using anchors. Buoylines are attached at both ends of the groundline and floats and flags are attached to the ends of the buoyline to mark the location of the gear. Traps are Korean conical traps of either 54 or 48 inch (1.37 or 1.22 m) bottom hoop diameter with a single webbed tunnel entrance. Traps are baited with a combination of frozen California squid (*Loligo* sp.) in mesh bait bags and frozen Pacific hake (*Merluccius productus*) loose in the trap. Fifty to eighty traps are attached at about 25 fm (46 m) intervals along a groundline. Traps are required to have a section of mesh closed with a single length of thin, untreated natural fibre that will deteriorate if the trap is lost. Beginning in 1999, traps were required to have two escape openings with an inside diameter of at least 3.5 inches (8.9 cm). Hook and line gear consists of 500 to 1500 hooks usually baited with squid on short leader lines attached at 1-2 fm intervals to the groundline.

C.2 Management by total allowable catch

The sablefish fishery was unregulated prior to 1981. Beginning in 1981, a TAC fishery control policy was used for a fishing year beginning Jan 1 and ending Dec 31. Management tactics applied to the fishery have varied considerably over the last two decades (Table C.1, Table C.2, Table C.3). With the exception of the annual TAC, fishing was unrestricted from 1981 to 1984. The total number of calendar days required to attain the TAC declined from 245 to 181 days during this period. From 1985 to 1987 the fishery was split into two openings, with a provision for a third opening if required to achieve the TAC. However, increased fishery participation and fleet efficiency made it difficult to predict the duration of the fishery. In 1988 and 1989 fishers were given a choice of one of seven 20 day openings (1988) or eight 14 day openings (1989). Alternative fishing times (Table C.1) were offered to allow individuals to choose an opening to take advantage of market conditions and to reduce conflicts with other fisheries such as Pacific herring (*Clupea harengus pallasi*) or Pacific halibut (*Hippoglossus stenolepis*). Fishery duration remained difficult for fishery managers to estimate because of variable participation by license holders and continued increases in fleet efficiency. As a consequence, total quota overruns increased to 29.8 and 21.6 percent in 1988 and 1989, respectively.

Allocations of sablefish are made for research, aquaculture, and First Nations uses. The balance of the TAC is allocated to commercial uses, with the trawl allocation comprising 8.75 percent of the commercial quota (Table C.1).

C.3 Management by individual vessel quota

In 1990, Individual Vessel Quota (IVQ) management was introduced and remains in effect through the 2003/2004 fishing year. Each eligible vessel was allocated a portion of the quota using the weighted sum of historical vessel catch and overall vessel length:

- 70 percent of a license holder's highest landings in 1988 and 1989 divided by the total catch multiplied by the quota;
- 30 percent of the overall vessel length divided by total length of all licensed vessels multiplied by the quota.

The IVQ policy included temporary and permanent transferability of quota among quota holders as described in management plans (e.g. Fisheries and Oceans 2003, their Appendix 1). The discrepancy between "K" fleet TAC and landings has been small since the inception of the IVQ program.

The directed sablefish "K" fishery was closed January 18, 2002 due to concern about stock decline invoked by significantly reduced catch rates observed during the fall 2001 standardized survey. The fishery was re-opened on March 18, 2002 with a revised quota of 2,800 t for the 2001/2002 fishing year, down 1,200 t from the 4,000 t quota adopted prior to the start of the fishing year. A 2,450 t quota was adopted for the 2002/2003 fishing year (Table C.1, Table C.3). These fishing year quotas were implemented over a two year period in the following manner:

- Fishery managers combined the 2001/2002 and 2002/2003 TACs of 2,800 and 2,450 t, respectively, to yield a two-year sablefish TAC of 5,250 t;
- The directed sablefish "K" fleet allocation of the two-year TAC was 4,540 t after allocations to First Nations, scientific purposes, and the non-directed trawl fleet;

- A total of 3,567 t of sablefish was allocated to the quota holders at the start of the 2001/2002 fishing year, leaving 973 t for the 2002/2003 fishing year;
- Quota holders were permitted to allocate a total of 910 t of their 2001/2002 fishing year quota to the 2002/2003 fishing year;
- In addition, IVQ shortfalls in 2001/2002 of 10% were allowed to be "carried forward" into the 2002/2003 fishing year, i.e. sablefish that did not get caught in 2001/2002 was allocated into 2002/2003, in keeping with the rules of the IVQ program.

The objectives of these management measures were to (1) maintain fairness in the operation of the IVQ program, and (2) to distribute the two-year TAC over the 2001/2002 and 2002/2003 fishing seasons. The quota for the 2003/2004 fishing year was set at 3,000 t, based on increased standardized survey catch rates and other positive indicators.

C.4 Overage/Underage Rules

The concept of quota "carry-forward" was introduced as a management tactic in 1994 to accommodate individual quota overruns and shortfalls. The tactic allowed fish taken in excess of an individual's allowable quota (an "overage" rule) to be subtracted from quota allocated in the next fishing year. An "underage" rule was also introduced by allowing a "carry-forward" of uncaught fish into the next fishing year. For example, the 2002/2003 management plan (Fisheries and Oceans 2002, Appendix 1, Section 1.5.4) described the following rules:

- **Overage or overrun rule**. A licensed sablefish vessel may exceed its IVQ by the greater of up to five (5) percent of the vessel IVQ or one thousand pounds. The amount of the overrun will be subtracted from the vessel IVQ in the following fishing year. Sablefish landed in excess of these limitations are relinquished to the managing agency and the amount is subtracted from the vessel IVQ in the following fishing year;
- **Underage or shortfall rule**: A licensed sablefish vessel that is ten (10) percent or less under the vessel IVQ may add the shortfall to the vessel IVQ in the following fishing year. Any shortfall in excess of ten percent is forfeited.

Any overage must be made up in the fishing year following the overrun, and quota shortfalls can be carried forward only into the fishing year following the shortfall. From 1990 to 1993, revenue from all overages was relinquished to the Government of Canada, as is now the case for overages in excess of the allowable limits.

The overage and underage rules were intended to impart flexibility to individual fishers such that the net departure from the annual TAC by the fleet in aggregate is zero. In actual practice, overage and underage rules have acted at the aggregate level as intended. Consider, Figure C.1 where the top two panels show each vessel's landings plotted against individual quota for the 2000/2001 and 2001/2002 fishing years, respectively. Departures from the solid line in each panel represent an individual quota overage or underage. The distribution of differences between the landings and the allocated quota are summarized using boxplots in the two lower panels of the figure. The sum of the overages and underages is less than zero in both fishing years, with most quota holders landing less than their actual allocations. In view of the ramping down of the quota in 2002/2003 (Table C.3), this analysis was not conducted for 2002/2003 data since they are not representative of the normal operation of the quota system.

The details of the rules have changed in two ways since their inception. First, the allowable percentages of overage and underage have been assigned various combinations of 5 and 10 percent over time (Table C.2). Second, the percentage overage was applied to the quota *remaining* to the vessel when the overage occurred until 1999, when the percentage was applied to the vessel's *total* quota (Table C.2).

If all quota holders behave similarly in a given fishing year, the following scenarios bound the extremes of the total harvest possibilities within the directed sablefish fishery *for a given year*:

- The catch is 10 percent less (possibly more if quota is forfeited) than the current TAC provided no quota was carried forward from the previous fishing year, i.e. all quota holders have a 10 percent shortfall in the current year but landed their quotas exactly in the previous year;
- The catch is greater than the TAC by 5 percent of the current fishing year quota using the overage rule, plus an additional 10 percent of the previous fishing year TAC by virtue of fish carried forward using the underage rule.

In the latter scenario, the percentage by which the current TAC is exceeded depends on the relative magnitude of TACs in the current and previous fishing years. If the current TAC were smaller than the previous TAC, the percentage overrun of the current TAC would be greater than 15 percent, and vice versa. Under scenario 2, and assuming that all permitted sablefish are caught in the current year, each IVQ in the succeeding fishing year would be reduced by an amount equivalent to 5 percent of the current year IVQ.

C.5 Other management tactics

A minimum size limit of 55 cm fork length (39 cm from origin of first dorsal fin to the fork of the tail) was introduced in 1994 (Table C.2). In 1999 the fishing year was 19 months long to accommodate a change in the fishing year from a January 1 to December 31 period to an August 1 to July 31 period. A requirement for all traps to be equipped with two openings (typically stainless steel escape rings) in the side-walls of not less than 89 mm (3.5 in) diameter was initiated in 1999. This change followed voluntary use of escape rings by some fishers in 1998 and was intended to reduce the catch of juvenile sablefish. The market preference is for a sablefish of about 65 cm fork length or greater.

C.6 Fishery monitoring measures

Independent monitors at designated landing sites have validated all sablefish landings since 1990. Data collected by the dockside monitoring program (DMP) include landed weight by species, product type, vessel, gear, and area fished. Fisher logbooks were mandatory beginning in 1990. Data recorded include set location, gear, effort, date and time of each deployment and retrieval of the gear, catch weight by species, product and use of catch.

There has been relatively little at-sea observer coverage in the offshore sablefish fishery, excluding fishing at seamounts. For the 2002/2003 and 2003/2004 fishing years, at-sea observer coverage was initiated with the objective of observing approximately 15 percent of the fishing days. Observer coverage was initiated to provide improved estimates of catch by species, although it is anticipated that opportunities to collect information on the number and size of retained and discarded sablefish and biological samples will assist stock assessment as the observer program matures.

Commercial trawl vessels that fish under a "T" category license receive an allocation of the sablefish TAC (Table C.1). A 100 percent at-sea observer program was regulated for the trawl fishery beginning in 1996, with the exception of vessels operating under the Option B fishery in the Strait of Georgia and those vessels fishing the domestic hake fishery, where 10 percent observer coverage has been in place beginning with the 2002/2003 fishing year. Dockside validation of landings has been regulated since 1994 for most trawl landings except for Pacific hake and Strait of Georgia Option B (Rutherford 1999).

C.7 Literature Cited

Fisheries and Oceans Canada. 2002. Integrated fishery management plan: sablefish, August 1, 2002 to July 31, 2003. Fisheries and Oceans Canada. 50 p.

Fisheries and Oceans Canada. 2003. Integrated fishery management plan: sablefish, August 1, 2003 to July 31, 2004. Fisheries and Oceans Canada. 82 p.

Rutherford, K.L. 1999. A brief history of GFCATCH (1954-1995), the groundfish catch and effort database at the Pacific Biological Station. Can. Tech. Rep. Fish. Aquat. Sci. 2299: 66 p.

Table C.1 Sablefish management history. Note that the 2003/2004 data are current to Nov 11, 2003.

Year	Fishery	Assessment Yield Rec.	TAC	K Quota	T Quota	First Nations	Science	Total Landings	Date Open	Date Closed	Days Open	FY Days	"K" Vessels Trap	"K" Vessels Longline
1981	Derby		3500	3190	310			3830.2	01-Feb-81	04-Oct-81	245	245	16	
1982	Derby		3500	3190	310			4027.4	01-Feb-82	22-Aug-82	202	202	15	
1983	Derby		3500	3190	310			4336	01-May-83	26-Sep-83	148	148	14	
1984	Derby		3500	3190	310			3827.4	01-Mar-84	22-Aug-84	174	174	13	
1985	Derby		4000	3650	350			4192.7	01-Feb-85	08-Mar-85	35	92	17	
									29-Mar-85	02-May-85	34			
									19-Jul-85	11-Aug-85	23			
1986	Derby		4000	3650	350			4448.1	17-Mar-86	21-Apr-86	35	63	20	
									12-May-86	09-Jun-86	28			
1987	Derby		4100	3740	360			4630.5	16-Mar-87	10-Apr-87	25	45	19	
									01-Sep-87	21-Sep-87	20			
1988	Derby		4400	4015	385			5402.6	06-Mar-88	26-Mar-88	20	140	24	
									05-Apr-88	25-Apr-88	20			
									05-May-88	25-May-88	20			
									05-Jun-88	25-Jun-88	20			
									05-Jul-88	25-Jul-88	20			
									02-Aug-88	22-Aug-88	20			
									04-Sep-88	24-Sep-88	20			
1989	Derby		4400	4015	385			5324	14-Feb-89	28-Feb-89	14	112	30	
									14-Mar-89	28-Mar-89	14			
									14-Apr-89	28-Apr-89	14			
									10-May-89	24-May-89	14			
									10-Jun-89	24-Jun-89	14			
									06-Jul-89	20-Jul-89	14			
									04-Aug-89	18-Aug-89	14			
									15-Sep-89	29-Sep-89	14			
1990	IVQ		4670	4260	410			4904.9	21-Apr-90	31-Dec-90	255	255	15	18
1991	IVQ	2,900-5,000	5000	4560	440			5112.4	01-Jan-91	31-Dec-91	365	365	14	14
1992	IVQ	2,900-5,000	5000	4560	440			5007.5	01-Jan-92	31-Dec-92	366	366	16	11

Year	Fishery	Assessment Yield Rec.	TAC	K Quota	T Quota	First Nations	Science	Total Landings	Date Open	Date Closed	Days Open	FY Days	"K" Vessels	
													Trap	Longline
1993	IVQ	2,900-5,000	5000	4560	440			5109.8	01-Jan-93	31-Dec-93	365	365	14	9
1994	IVQ	2,900-5,000	5000	4521	433			5001.5	01-Jan-94	31-Dec-94	365	365	15	9
1995	IVQ	2,725-5,550	4140	3709	356		29.48	4178.8	01-Jan-95	31-Dec-95	365	365	15	15
1996	IVQ	690-2,580	3600	3169	304		81.65	3470.5	01-Jan-96	31-Dec-96	366	366	12	11
1997	IVQ	6,227-16,285	4500	4023	386		45.36	4142.0	01-Jan-97	31-Dec-97	365	365	13	13
1998	IVQ	3,286-4,761	4500	4023	386		45.36	4591.7	01-Jan-98	31-Dec-98	365	365	13	12
1999/ 2000	IVQ	2,977-5,052	4500	6395	386		45.36	7010.9	01-Jan-99	31-Jul-00	578	578	12	19
2000/ 2001	IVQ	3,375-5,625	4000	3555	350		45.36	3882.3	01-Aug-00	31-Jul-01	365	365	12	23
2001/ 2002	IVQ	4,000	2800	2657	342	45	45.36	2388.4	01-Aug-01	31-Jul-02	365	365	12	21
2002/ 2003	IVQ	4,000, revised to 2100-2800	2450	1883	206	45	45	2298.1	01-Aug-02	31-Jul-03	365	365	8	20
2003/ 2004	*IVQ*	*Decision table*	*3000*	*2647*	*254*	*45*	*54*	*NA*	*01-Aug-03*	*31-Jul-04*	*365*	*365*	*5*	*16*

Table C.2 Narrative of significant annual events for the directed sablefish fishery.

Fishing Year	Management Events
1981	• Fishing season defined Jan. 1 to Dec. 31 • Limited-entry (48 licenses) "K" license tab introduced • Longline hook or trap gear • Fishery unrestricted until TAC achieved
1988	• Each "K" licensed vessel permitted to fish in one of seven scheduled 20 day openings between Mar. and Sep.
1989	• Each "K" licensed vessel permitted to fish in one of eight scheduled 14 day openings between Mar. and Oct.
1990	• Individual vessel quotas introduced in directed sablefish "K" fishery • Quota allocated among 48 "K" license holders • Mandatory fisher logbooks instituted • Mandatory dockside validation of landings instituted
1994	• Overage of up to maximum of 1,000 lbs or 5 percent of ***vessel's remaining quota*** permitted; • Underage of 5 percent or less of vessel's quota permitted; • Minimum size limit of 55 cm fork length introduced (39 cm from origin of first dorsal fin to fork of the tail)
1995	• Overage of up to maximum of 1,000 lbs or 10 percent of ***vessel's remaining quota*** permitted; • Underage of 10 percent or less of vessel's quota permitted; • 29.48 t removed from TAC for scientific purposes
1996	• Overage/underage rules unchanged; • 81.65 t removed from TAC for scientific purposes
1997	• Overage/underage rules unchanged; • Individual vessel quotas introduced in non-directed trawl "T" fishery • Trawl fishing year changed to Apr. 1 to Mar. 31 from Jan. 1 to Dec. 31 • 45.36 t allocated from TAC for scientific purposes
1998	• Overage/underage rules unchanged; • Voluntary use of escape rings in traps by some fishers • 45.36 t allocated from TAC for scientific purposes

Fishing Year	Management Events
1999	• Overage/underage rules unchanged; • "K" fleet fishing year changed to Aug. 1 through Jul. 31 from Jan. 1 to Dec. 31 • Fishing season defined as 19 months long, quota adjusted accordingly • Escape rings in traps regulated of inside diameter not less than 8.89 cm (3.5 inches) and 2 rings per trap • 45.36 t allocated from TAC for scientific purposes
2000/2001	• Overage up to 5 percent of a ***vessel's quota*** permitted; • Underage of 10 percent or less of a ***vessel's quota*** permitted; • 45.36 t allocated from TAC for scientific purposes
2001/2002	• Overage/underage rules unchanged; • Fishery closed Jan. 18, 2002 following preliminary survey results that suggested significant coastwide decline in abundance • Annual TAC adjusted mid-season from 4,000 t to 2,800 t • Fishery re-opened Mar. 18, 2002 • Trawl allocation adjusted to accommodate mid-season adjustment • 25 t allocated from TAC for scientific purposes
2002/2003	• Overage/underage rules unchanged; • Mandatory at-sea observer coverage instituted for approximately 15 percent of fishing days • Government-industry collaborative management agreement signed for 5 year period • 45 t allocated from TAC for scientific purposes
2003/2004	• Overage/underage rules unchanged; • Mandatory at-sea observer coverage instituted for approximately 15 percent of fishing days • 54 t allocated from TAC for scientific purposes

Table C.3 TACs and allocations for the 2001/2002 to 2003/2004 fishing years.

TAC Parameters	2001/2002	2002/2003	2-Year Totals	2003/2004
TAC	2800	2450	*5250*	3000
Scientific purpose	25	45	*70*	54
First Nation allocation	45	45	*91*	45
Trawl "T" allocation	342	206	*548*	254
Sablefish "K" Allocation	3567	973	*4540*	2647
Carry Forward	(910)	910	*0*	0
Final "K" Allocation	2657	1883	*4540*	2647

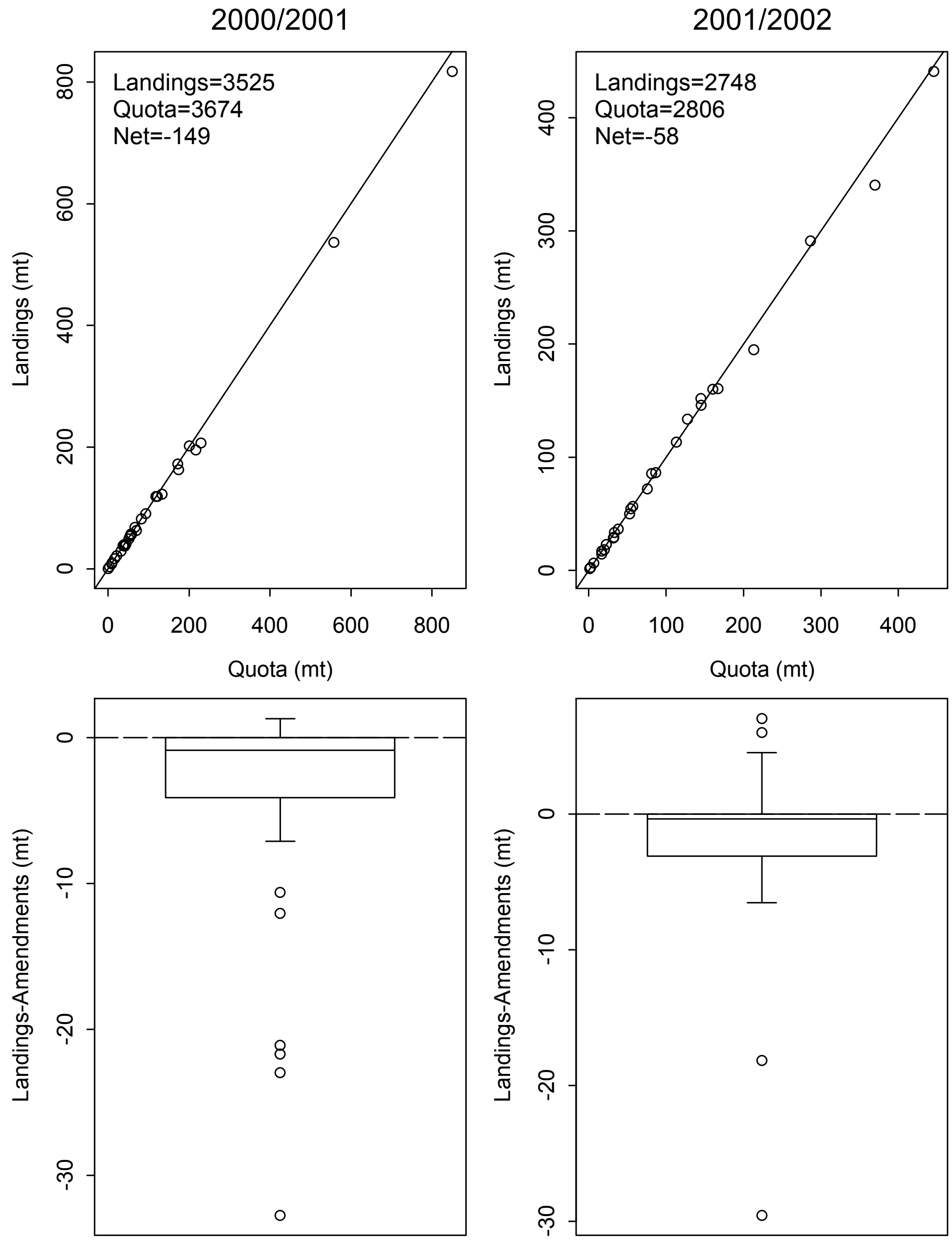


Figure C.1 Quota overages/underages (t) for the 2000/2001 and 2001/2002 fishing years.

APPENDIX D STOCK ASSESSMENT HISTORY

D.1 BACKGROUND D-1
D.2 REVIEW OF STOCK ASSESSMENT APPROACHES IN BRITISH COLUMBIA D-2
D.3 IMPEDIMENTS TO STOCK ASSESSMENT D-2
D.4 PROGRESS ON RESOLVING IMPEDIMENTS TO STOCK ASSESSMENT D-4
D.5 LITERATURE CITED D-7

D.1 Background

Development of a long-term approach to sablefish stock assessment depends on understanding the evolution of stock assessment methodology in B.C. and why various data selection and modeling choices were made over time. It also depends fundamentally on the specification of fishery objectives for sablefish. In this section the history of sablefish assessment in B.C. is reviewed. Structural impediments to integration of available assessment data are identified, and steps to resolving these difficulties through existing or planned work are described.

Management and assessment of sablefish in British Columbia is currently conducted under the auspices of a collaborative agreement (Joint Project Agreement 2002) between the Government of Canada and the Canadian Sablefish Association. This legal agreement is in effect from August 1, 2002 to July 31, 2006, and provides for collaborative development of research, stock assessments and management advice. An annual work plan for science and assessment activities is developed by the Science Coordinating Committee of the Joint Project Agreement (JPA).

Goals for the sablefish fishery, as listed in the fishery management plan (Fisheries and Oceans Canada 2002, 2003), include the following:

1. To ensure conservation and protection of sablefish stocks through the application of scientific management principles applied in a risk averse and precautionary manner based on the best scientific advice available;
2. Provide opportunities for commercial fishers to harvest sablefish while employing adequate controls and monitoring in the commercial fishery to ensure the commercial TAC is not exceeded.

Quinn and Deriso (1999) defined *goals* as broad, conceptual statements of fisheries management desires. Fishery *objectives*, in the sense of the specific elements of the management system that allow the goals to be achieved, are not defined for sablefish. Discussion of management requirements for sablefish in British Columbia has not produced objectives that can be translated into operational fishery decision rules, although various reference points have been applied in the course of sablefish assessment as described below. The joint work planning process undertaken under the JPA supported development of sablefish fishery objectives for 2002/2003. This work was initiated in 2003 and is anticipated to be ongoing in 2004/2005.

D.2 Review of stock assessment approaches in British Columbia

Beginning in the early 1990s, sablefish assessment methodology in B.C. experienced a notable increase in the complexity of models applied to the catch-at-age and tag-recovery data. This work culminated in an integrated catch-at-age mark recapture model presented in the late 1990s, after which the analyses became markedly simpler (Haist et al. 1999, Haist and Hilborn 2000, Kronlund et al. 2003). An historical synopsis of data inputs, assessment methodology, PSARC advice, yield, and TACs is presented in Table D.1. Information presented in Table D.1, and in the remainder of this section, was drawn from unpublished stock assessment working papers, Canadian Stock Assessment Secretariat Research Documents, annual reports of the Pacific Stock Assessment Review Committee, and Canadian Science Advisory Secretariat Proceedings. The "Year" column of the table lists both the year of the stock assessment and the fishing year (italics) to which the assessment applied. The "Data Sources" column lists only data actually used in analyses that determined yield options. Other analyses may have been presented in the document to provide ancillary results, or to assess the validity of assumptions made in the course of yield determination.

D.3 Impediments to stock assessment

Ageing data. Routine ageing of sablefish at the Pacific Biological Station was halted in 1997 due to concern over the accuracy of ages determined through the otolith burnt section method. Consequently, catch-at-age information is not available after 1996 for assisting the estimation of relative year class strength and population age structure. As an alternative, Beamish and McFarlane (2000) proposed otolith thin section ageing for sablefish. Thin sectioning of otoliths is not a new technique, but results for sablefish had not been reported prior to the work of Beamish and McFarlane (2000). Ageing of sablefish has been considered difficult (Heifetz et al. 1998, Beamish and McFarlane 2000). The difficulties are attributed to high variability in growth patterns among otoliths, difficulty in determining the first three years of growth, confusing growth patterns in the "transition" zone from ages 3 to 10, and interpretation of annuli at the periphery of the otolith. In particular, Heifetz et al. (1998) noted misinterpretation of an ambiguous growth check immediately following the first annulus, and misinterpretation of whether the most recent year's annulus had been formed. The small size of sablefish otoliths does not represent an impediment in most cases.

Tagging program. Assessments of sablefish through the late 1990s relied primarily on tag-recovery information to index stock abundance due to concerns over the use of commercial catch rates as an abundance index. Another potential advantage of tagging data is the ability to determine movement or migration both spatially and temporally. Implausible model results obtained from modeling attempts in the late 1990s prompted the adoption of a simplified tag-recovery model in 2000 (Haist and Hilborn 2000) that utilized tag returns only in the year following release.

Tag releases have been large, and tag-reporting rates are thought to be high (Beamish and McFarlane 1988, Appendix B in Haist et al. 1999). Haist et al. (2001) argued that since the tags are applied primarily at the same depths where most of the fishing takes place, the estimated exploitation rates for the entire stock are biased high and the true exploitation rates are lower. In turn, this implies the biomass estimates are biased low (they reflect the vulnerable adult component of the stock) and the true biomass is higher than indicated by the tagging model.

The 1990 to 2003 tag-recovery data fail to meet the assumptions of traditional tagging models, at least one of which must be satisfied:

1. *Random tag application*. Tags are applied in locations and depth zones that represent the "core" of commercial fishing effort (over 80 percent of tags are applied between 250 and 450 fm);
2. *Random tag recovery*. Only recoveries from the trap fishery are utilized which has restricted spatial and depth distribution relative to the population distribution;
3. *Complete mixing of tags*. Table 9 in Haist et al. (2001) documented high correlation of tag recoveries with the site of tag release so that complete mixing does not apply to at least one component of the fish tagged.

Furthermore, most tagging models make the assumption that the population is closed, so that emigration or immigration of fish is not incorrectly interpreted as mortality or recruitment. The northern B.C. stock, in particular, is not a closed population due to exchange of fish with Alaska (see Beamish and McFarlane 1988, McFarlane and Saunders 1997, Kimura et al. 1998, Haist et al. 1999). Thus, if the tagging program is to reflect the offshore population and meet basic model assumptions, the design of the program must be changed and U.S. tag return data utilized.

Tag disappearance rates. Young fish tagged in Hecate Strait in the late 1970s had a high probability of emigration from B.C. (McFarlane and Saunders 1997, McFarlane and Beamish 1983). This effect has been demonstrated most strongly at smaller sizes and younger ages than is typical of sablefish found in the commercial catch. Thus, this emigration has the same net effect as a size and age-dependent rate of natural mortality that is higher for pre-recruits than for adults. These results were observed for exceptional year classes spawned in the late 1970s and there has been no tagging in Hecate Strait since that time, so it is not clear whether the same movement pattern has persisted. Quantitative attempts to cope with this effect involved a two-stage mortality function that attempted to mimic the higher emigration rates of pre-recruited sablefish (Saunders et al. 1995, 1996). However, this approach was abandoned after 1996 due to incomplete information on the age-specific characteristics of the emigration.

Haist et al. (1999, their section 2) conducted an analysis of tag-recovery data that suggested the instantaneous tag disappearance rate in the first five years after release was high (Z=0.5) but declined considerably thereafter to about Z=0.2. This feature of the data is consistent with a hypothesis of fish moving to an unfished area, or to an area of reduced vulnerability. The possibility of sablefish abundance in B.C., particularly in the north, being driven by fluctuations in the much larger Alaskan sablefish population means that immigration into or emigration from B.C. waters needed to be much better understood to properly reconstruct population abundance. The integrated catch-at-age and tag-recovery models of 1996 and 1997 treated the B.C. population as closed, and could not quantitatively accommodate fluxes of fish from outside the defined stock area. An attempt to address movement out of the Canadian zone was developed for 1998 (Haist et al. 1999), but the model tried to resolve the high disappearance rate of fish in the first five years after tagging by assigning large amounts of biomass into southern deep-water and Alaska strata. Survey data suggest abundance of sablefish is relatively low in deep-water (e.g., Wyeth and Kronlund 2003). The model behavior was considered implausible, so that work on models that incorporate tag movement were placed in hiatus until the underlying data can be improved.

Standardized Survey. From a statistical perspective, the design of the standardized survey series is compromised by the lack of replication within each combination of depth stratum and locality, and the brevity of the time series relative to the longevity of sablefish. The protocol for selecting fishing sites has been *ad hoc* within the survey localities, and does not require random set location or repeated visits to the same set locations over time. However, the credibility of the survey as an abundance index can be drawn from the consistency in survey protocol over time and by similarities in the pattern of the survey catch rate time series from 1990 to 2003 among most locations and within most depth strata. Also, the general coincidence of the survey catch rates, commercial trap catch rates, and tagging-based abundance estimates noted by Haist et al. (2001), Kronlund et al. (2003) and reiterated in this document provides support for the indexing survey trends.

D.4 Progress on resolving impediments to stock assessment

Ageing data: A research project was initiated in July 2002 to evaluate the relative performance of Otolith Burnt Sections (OBS) and Otolith Thin Sections (OTS). Preliminary results based on paired OBS and OTS readings of 188 sablefish otoliths showed that:

1. OTS age readings are consistently greater than OBS age readings for fish less than about 20 years. For ages greater than 20 years differences did not exhibit a consistent bias;
2. Differences between OTS and OBS readings increase with OBS age readings.

The relative lack of known age specimens for validation of the competing methodologies means that no clear choice between methods has emerged. Beamish and McFarlane (2000) noted several interpretation issues with OTS preparations related to distinguishing annuli from growth checks. A growth check is a mark that does not form annually but reflects environmental or physiological changes (e.g., stress during spawning). They concluded that OBS and OTS sections be used in concert to interpret annuli since the OTS method showed growth patterns with greater clarity, but the OBS method assisted distinguishing annuli from checks. Research on sablefish ageing was identified in the 2003/2004 sablefish work plan developed under the JPA.

Tagging program. It is not possible to randomize tag recoveries and there is evidence to refute complete mixing of sablefish (Haist et al. 2001). Thus, random tag application is the only avenue available to meet the basic assumptions of standard tag recovery analyses. In 2002, tagged sablefish were released using two protocols:

1. a "**traditional**" tag release protocol, consistent with historical practice, to allow future analyses consistent with previous analyses; and
2. a new "**systematic**" design that attempts to distribute the tagged sablefish throughout the offshore population in proportion to local abundance.

The 2002 assessment survey marked the beginning of attempts to emulate the "traditional" spatial and depth distribution of tag releases since 1999, but with a reduced number of releases. For the systematic tagging protocol, the localities and depth strata used for the indexing program were adopted, but traps were baited with squid and hake to optimize the number of releases per set. Another step taken in 2002 was to test the feasibility of randomly chosen set positions for trap gear. This test was successful, and no serious impediments to randomly chosen set positions were identified.

In 2003, a pilot study was implemented to test a stratified-random survey design (Cochran 1977) for tagging sets. If successful, the long-term plan of the Science Coordinating Committee (Sablefish JPA 2002) is to integrate the existing standardized survey and tagging sets into a single stratified-random survey design. Random sampling is a requisite design feature for unbiased estimation of the annual abundance indices and construction of design-based confidence intervals for annual index points. Stratification can increase the precision of survey estimates, provide administrative convenience, and insurance against loss of the entire survey should problems be experienced in a particular stratum.

A total of 75 sets were allocated to the stratified random tagging survey in 2003 (Appendix G). The objective of the design was to randomly release tagged fish across depth and spatial strata inhabited by sablefish on the "offshore" B.C. coast. The design had the following characteristics:

- The offshore area was partitioned into 5 spatial strata with 3 depth strata within each spatial stratum for a total of 15 strata (Appendix G);
- For 2003, a total of 5 replicates was assigned to each stratum;
- The sampling unit selected at random within each stratum was a 2 km by 2 km square;
- The tagging set was required to be contained within the requisite depth stratum in each square;

- Sablefish caught in 50 percent of the traps were tagged in order to apply tags in proportion to the catch rate; the remainder of the traps were sampled for biological characteristics;
- Each string of gear was comprised of 25 traps baited with 2 lbs of frozen squid plus 10 lbs of frozen offshore Pacific hake (*Merluccius productus*);
- The target soak time was 24 hours.

The resolution of available bathymetric data is such that fairly broad depth strata were specified to ensure that the intended depth interval could be achieved, and the sets were required to lie within a 2 km by 2 km square. Improvements to the resolution of bathymetric data would allow finer resolution of depth strata and reduction of the area of sampling units for the sets.

The Type 1 "traditional" tagging sets were conducted in 2003, and will be maintained for several years to allow calibration of the historical tag-recovery time series to a new time series established using random release sites derived from a stratified random survey design.

Tag disappearance rates. To date, all models that have been developed to investigate movement of tagged B.C. sablefish have been based on transition matrices and assuming a Markovian process (Haist et al. 1997, 1998, 1999, Haist and Hilborn 2000). Movement was modeled as an annual process with large-scale spatial and depth strata. This type of model cannot be used to investigate certain aspects of sablefish dynamics that may be operating. These aspects include: (1) an apparent high probability that some sablefish remain close (scale of metres) to locations where they were originally caught for tagging (Haist et al. 2001), and (2) seasonal movement. These dynamics could be age and/or sex specific. A continuous model, based on diffusion dynamics and incorporating location-specific data on fishing effort, would allow investigation of alternative hypotheses about sablefish movement dynamics. This work was identified in the 2003/2004 sablefish work planning process.

Standardized survey. The placement of survey sets under the current protocol is not randomized, but rather is left to the discretion of the fishing master subject to positioning a set within each prescribed depth stratum and survey locality. The adoption of randomized fishing locations would decrease potential bias created by purposive selection of sites. However, randomly positioned sets are likely to result in lower catch rates on average, and would essentially restart the survey time series. Thus, the protocol for the standardized survey used beginning in 1990 will be continued for some time while the stratified random survey design piloted in 2003 for tagging is developed. After some years of overlap, calibration of catch rates obtained from the randomized survey design and the existing standardized survey series will be evaluated. If calibration is possible, the existing standardized survey will be discontinued and replaced by a combined tagging/indexing stratified random design.

D.5 Literature Cited

Beamish, R.J. and G.A. McFarlane. 2000. Reevaluation of the interpretation of annuli from otoliths of a long-lived fish, *Anoplopoma fimbria*. Fish. Res. **46**: 105-111.

Beamish, R.J. and G.A. McFarlane. 1988. Resident and dispersal behavior of adult sablefish (*Anoplopoma fimbria*) in the slope waters off Canada's west coast. Can. J. Fish. Aquat. Sci. **45**: 152-164.

Beamish, R.J. and G.A. McFarlane. 1983. Summary of results of the Canadian sablefish tagging program. p. 147-183. *In* Proceedings of the Second Lowell Wakefield Fisheries Symposium. Anchorage, AK. Alaska Sea Grant Report 83-8.

Cochran, W.G. 1977. Sampling techniques. Wiley, New York. 428 p.

Fisheries and Oceans Canada. 2002. Integrated fishery management plan: sablefish, August 1, 2002 to July 31, 2003. Fisheries and Oceans Canada. 50 p.

Fisheries and Oceans Canada. 2003. Integrated fishery management plan: sablefish, August 1, 2003 to July 31, 2004. Fisheries and Oceans Canada. 82 p.

Haist, V., Saunders, M.W., Hilborn, R., and M. Maunder. 1997. Sablefish stock assessment for 1997 and recommended yield options for 1998. Can. Stock Assess. Sec. Res. Doc. 97/146.

Haist, V., Fournier, D., and M.W. Saunders. 1999. Reconstruction of B.C. sablefish stocks, 1966-1998, and catch projections for 1999, using an integrated catch-age mark-recapture model with area and depth movement. Can. Stock Assess. Sec. Res. Doc. 99/79.

Haist, V., Hilborn, R., and M.W. Saunders. 1999. Sablefish stock assessment for 1999 and recommended yield options for 2000 and 2001. Can. Stock Assess. Sec. Res. Doc. 99/195.

Haist, V. and R. Hilborn. 2000. Sablefish stock assessment for 2000 and recommended yield options for 2001. Can. Stock. Assess. Sec. Res. Doc. 2000/157. 78 p.

Haist, V., Hilborn, R., and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. Can. Sci. Advisory Res. Doc. 2001/135. 54 p.

Heifitz, J., D. Anderl, N.E. Maloney, and T.L. Rutecki. 1998. Age validation and analysis of ageing error from marked and recaptured sablefish, *Anoplopoma fimbria*. **97**: 256-263.

Kimura, D.K., Shimade, A.M., and F.R. Shaw. 1998. Stock structure and movements of tagged sablefish, *Anoplopoma fimbria* in offshore northeastern Pacific waters and the effects of El Nino-southern oscillation on migration and growth. Fish. Bull. 96: 462-481.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

McFarlane, G.A. and M.W. Saunders. 1997. Dispersion of juvenile sablefish, *Anoplopoma fimbria*, as indicated by tagging in Canadian waters. *In* Biology and management of sablefish, *Anoplopoma fimbria*. p. 81-92. NOAA Technical Report NMFS 130.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality in northern anchovy. Amer. Fish. Soc. Symp. **6**: 66-82.

Quinn, T.J. and R.B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York. xv+542p.

Saunders, M.W., B.M. Leaman, G.A. McFarlane. 1995. Sablefish stock assessment for 1995 and recommended yield options for 1996. PSARC Working Paper G95-5.

Saunders, M.W., B.M. Leaman, V. Haist, R. Hilborn, and G.A. McFarlane. 1996. Sablefish stock assessment for 1996 and recommended yield options for 1997. PSARC Working Paper G96-5.

Wyeth, M.R. and A.R. Kronlund. 2003. Sablefish (*Anoplopoma fimbria*) research and assessment surveys conducted in British Columbia waters from 1996 to 2000. Can. Data Rep. Fish. Aquat. Sci. 1116: 130 p.

Table D.1 Historical synopsis of assessment methodology, yield, and TAC for British Columbia sablefish from 1990 to 2002. The **Year** column indicates both the year of the assessment and the fishing year (italics) to which the assessment applied. Yields for south (S) and north (N) stock areas are listed as provided in that year's assessment.

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1989 *1990*	• 1979-1989 total landings • 1979-1989 "K" trap landings and effort • 1979-1989 "K" logbook catch and effort • 1979-1987 age composition	• Examination of qualified trap CPUE data using a General Linear Model (GLM) by year, month, area, and skipper • Age-structured virtual population analysis (VPA) undated from 1988 assessment • VPA evaluated at M=0.1 and M=0.15 • Yield range based on application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules to a forward projection under low, medium and high recruitment assumptions	• Advisory document not available • Later Working Papers suggest standardization procedure criticized because variation explained was low (~30%)	2,900-5,000	4,670
1990 *1991*	• 1979-1990 total landings • 1979-1990 "K" trap landings • 1979-1990 "K" logbook catch and effort • 1979-1988 age composition	• Examination of observed CPUE series • Age-structured VPA forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment	• No explicit recommendations, endorsement of recommended yield by default	2,900-5,000	4,400
1991 *1992*	• 1979-1990 total landings • 1979-1990 "K" trap landings • 1979-1990 "K" logbook catch and effort • 1986, 1988-1990 trap survey catch and effort, fish age, length and maturity data • 1979-1989 age composition	• Age-structured VPA unchanged, forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment • Biomass estimated using CPUE from 1989, 1990 trap surveys expanded for area of depth strata, mean weight of survey fish and assumed fishing area of a trap (not used for yield determination) • Preliminary results of 1990 logbook data presented, noted set by set data available starting 1991	• Endorsed yield range but recommended against adopting high risk yield until incoming recruitment more fully assessed and model revised • Sequential VPA criticized due to data limitations, unreliable fishery-based abundance index	2,900-5,000	5,000

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1992 *1993*	• 1979-1991 total landings • 1979-1991 "K" trap landings • 1979-1990 "K" logbook catch and effort • 1986, 1988-1991 trap survey catch and effort, fish age, length and maturity data • 1979-1990 age composition	• Age-structured VPA , forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment • Biomass estimation used 1989 and 1991 trap survey data (not used for yield determination)	• Concluded no basis for modifying yield recommendations from 1991, but suggested managers avoid high risk catches • Reiterated criticism of VPA and lack of uncertainty estimates	2,900-5,000	5,000
1993 *1994*	• 1979-1992 total landings • 1979-1992 "K" trap landings • 1979-1992 "K" logbook catch and effort • 1986, 1988-1992 trap survey catch and effort, fish age, length and maturity data • 1979-1990 age composition	• Age-structured VPA unchanged with forward projection and application of $F_{0.1}$ and $F_{0.05}$ Y/R decision rules • VPA unchanged from 1989 assessment • Bayesian stock age/sex-structured model tested that included Beverton-Holt stock-recruitment, tuned to commercial CPUE (not used for yields) • Biomass estimation used 1989, 1991, and 1992 trap survey data (not used for yield determination)	• Endorsed yield recommendations on basis of lack of evidence to modify 1992 yields • Expressed concern that stock might be at lower abundance than previously believed, due to management and fishery impacts on commercial CPUE	2,900-5,000	5,000
1994 *1995*	• 1979-1993 "K" trap catch • 1979-1993 "K" trap CPUE conditioned on 250-450 fm and Apr-Dec • 1980-1993 catch at age proportions • Stock and sex-specific length at age data • Stock and sex-specific maturity at age • Pooled stock and sex length-weight data	• New stock synthesis (Methot 1990) stock reconstruction adopted to integrate commercial CPUE, catch-at-age, ageing precision, sex-specific, size-based selectivity (availability), time-based availability stanzas • Model tuned to abundance trend derived from selected commercial CPUE data • Yield derived using $F_{0.4}$ fishing mortality applied with M set to 0.05 and 0.1 • Biological and tagging data suggest north and south stock areas thus yields provided for south, north, and coast for first time	• Endorsed coast wide yield options • Recommended further development of stock synthesis model, particularly related to grouping of age classes and treatment of ageing errors	1,400-2,900 (S) 1,325-2,650 (N) 2,725-5,550 (C)	5,000

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1995 *1996*	• 1979-1994 catch • 1979-1994 "K" trap CPUE conditioned on 250-450 fm and Apr-Dec • 1980-1994 catch at age proportions • Stock and sex-length at age data • Stock and sex-specific maturity • Pooled stock and sex length-weight data	• Stock synthesis stock reconstruction with two-stage natural mortality function, catch-at-age, ageing imprecision, sex-specific size-based selectivity (availability), time-based availability stanzas • Model tuned to abundance trend derived from selected commercial CPUE data • Yield derived using $F_{0.4}$ fishing mortality applied with M set to 0.05 and 0.1 • Biological and tagging data suggest north and south stock areas	• Endorsed yield recommendation on basis of decline in reconstructed biomass and TAC set at high risk yields in recent years • Requested support for north and south stock areas be provided due to increased management complexity • Noted independent review of assessment was requested by industry	465-1,580 (S) 225-1,000 (N) *690-2,580* (C)	4,100
1996 *1997*	• 1980-1995 total catch • 1980-1995 catch at age proportions • 1991-1992 tag releases • 1991-1995 tag recoveries related to 1991-1992 releases	• New catch-at-age stock reconstruction with age-sex specific selectivity, plus group at age class 15 (down to age class 10) • Model tuned to new abundance index based on exploitation rates from independent tag-recovery model • Commercial CPUE questioned as abundance index due to frequent changes in management regime (IVQs), change in baiting practices (hake added to squid) • Yield derived using F=0.12 corresponding to $F_{0.40}$ to $F_{0.45}$ range identified by spawning stock biomass per recruit analysis as appropriate • Stock synthesis model of 1994-1995 run in parallel produce similar biomass trajectory but lower yield ranges	• Advisory document not available • Other documentation suggests concern about high sensitivity of model to number of age classes modeled, lack of depth stratification, impacts of changes in depth distribution on age samples	2,643-8,575 (S) 3,584-7,710 (N) *6,227-16,285* (C)	3,600

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1997 *1998*	• 1980-1996 total catch (1960-1996 for some analyses), depth and stock stratified • 1980-1996 catch at age proportions primarily from research surveys • 1990?-1996 index survey CPUE • 1980-1996 tag releases and associated tag recoveries	• New mark-recapture model incorporating fish movement between spatial and depth strata • New integrated catch-at-age mark-recapture model limited to movement out of the assessment region • Separate analyses for north and south stock areas on evidence from tag returns that recruitment is from different sources	• Concern expressed about difference in results from mark-recapture model (abundance decline) and integrated catch-at-age recapture model (abundance stable) • Noted model-derived abundance trend contradicted CPUE trends from survey and fishery • Noted need for further model development but questioned whether data contained enough information for this purpose • Suggested base model should not be used for management • Recommended spawner-recruit analysis be updated	2,131-3,176 (S) 1,155-1,585 (N) *3,286-4,761* (C)	4,500
1998 *1999*	• 1980-1997 total catch (1960-1996 for some analyses), depth and stock stratified • 1980-1995 catch at age proportions primarily from research surveys • 1988(?)-1997 index survey CPUE • 1979-1997 tag releases and associated tag recoveries, treated as a reduced (1991-1996 releases) and full (add 1979-1996 releases) tagging dataset	• Integrated catch-age mark-recapture (Bayesian) model with area and depth movement • Spatially and sex disaggregated age-structured model (age 15+ group) • Availability of fish, including tagged fish, was a function of age and sex • Single stock model with movement between BC regions and BC and US • Coast treated as 6 regions: south and north by shallow, mid, and deep depths • A 7th region was the US (AK+lower48) • Assumed recruitment restricted to two shallow depth regions • Model tuned using tagging based exploitation rates (reduced & full datasets split by 1979-96 and 1991-1996 releases • Natural mortality fixed at m=0.08	• Working paper recommended a yield from low-mid recruitment options as stock predicted to decline slowly under all scenarios (3,518 to 3972 mt at current F, 2977 to 4527 mt over all scenarios) • PSARC noted model was highly complex and the large discrepancy in biomass trajectories between the two tagging data sets • PSARC recommended yield options over full range of scenarios presented in working paper	2,977-5,052	4,500

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
1999 *2000/ 2001*	• 1980-1998 total catch (1960-1996 for some analyses), depth and stock stratified • 1980-1995 catch at age proportions primarily from research surveys • 1990-1998 index survey CPUE • 1979-1997 tag releases and associated tag recoveries, treated as a reduced (1991-1996 releases) and full (add 1979-1996 releases) tagging dataset	• Integrated catch-age mark-recapture (Bayesian) model with area and depth movement as in 1998 • Model modified for alternative migration (proxy for immigration into Canada) • Altered trap retention selectivity • Age classes changed to 2 through 13+ • Analysis of tag reporting rates, and first use of recoveries in first year of release only in deriving exploitation rates	• Cautious endorsement to analyses presented, noted model needed development citing high uncertainty • Concluded no evidence to alter 1999 yield recommendation • Noted current removals from north may not be sustainable • Recommended consideration of different exploitation rates for north and south stocks	1,275-2,125 (S) 2,100-3,500 (N) 3,375-5,625 (C)	4,500
2000 *2001/ 2002*	• 1992-2000 tag-recoveries in 1st release year • 1988-1999 index survey CPUE • 1990-1999 total catch • 1990-1999 "K" trap catch • 1990-1999 "K" trap logbook CPUE	• Integrated catch-age mark-recapture (Bayesian) model with area and depth movement as in 1999 • Impacts of escape rings on fish sorted for tags analyzed • Tag shedding rate estimated • Estimated abundance trends based on tag returns in the year following tagging using a simple Petersen-type estimator.	• Concurred catches in range 3,700 to 4,500 tons unlikely to decrease stock biomass in 2001/2002 • Accepted yield recommendation of 4,000 t • Recommended review of stock structure implications of distinct north and south stock management units	4,000	4,000 Revised Mar 2002 to 2,800

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
2001 *2002/ 2003*	• 1992-2001 tag-recoveries in 1st release year • 1988-2000 index survey CPUE • 1990-2000 total catch • 1990-2000 "K" trap catch • 1990-2000 "K" trap logbook CPUE	• Complex tagging and integrated catch-at-age mark-recapture models of 1997-2000 in hiatus • Comparison of CPUE trends and tag derived exploitation and abundance trends • No age-structured population dynamics • Modified spawning biomass per recruit simulation identified vulnerable biomass harvest rates of 0.06-0.11 (south) and 0.07-0.14 (north) • Estimated abundance trends based on tag returns in the year following tagging using a simple Petersen-type estimator. • Tag analysis estimates of harvest rate are 0.1-0.13 over 1990s	• Accepted low and stable stock status • Accepted yield recommendation of 4,000 t • Agreed future management should incorporate decision rules	4,000 Nov 2001 Revised to 2,800 Jan 2002	2,450
2002 *2002/ 2003*	• 1992-2002 tag-recoveries in 1st release year • 1990-2001 index survey CPUE • 1990-2001 total catch • 1990-2001 "K" trap catch • 1990-2001 "K" trap logbook CPUE	• Comparison of CPUE trends and tag derived exploitation and abundance trends • No age-structured population dynamics • Tag analysis estimates of harvest rate are 0.1-0.13 over 1990s • Increased emphasis on indexing survey • Cautionary yield reduction recommended to address concerns over continued decline in abundance since mid-1990s	• Recommended approximately equal weighting of bounds implied by indexing survey (2,100 t) and tag recovery model (4,000 t) respectively, i.e., 2,800 t. • Recommended that yield adopted for 2001/2002 be carried forward into 2002/2003 • Cautioned against using most recent survey or tagging datum • Requested all relevant data to be considered for new analyses	2,800	2,450

Year	Data sources	Methodology	PSARC Science Advice	PSARC Yield (mt)	Quota (mt)
2003 *2003/ 2004*	• 1992-2002 tag-recoveries in 1st release year • 1990-2002 index survey CPUE • 1990-2002 total catch • 1990-2002 "K" trap catch • 1990-2002 "K" trap logbook CPUE • Indicators from west coast Vancouver Island shrimp survey, Hecate Strait survey, thornyhead survey, IPHC survey, U.S. triennial survey, US stock assessments	• Evaluation of commercial trap, indexing survey, tag derived abundance indices • No age-structured population dynamics • New monthly tagging model that fits tag recoveries in the first year following release • Simple biomass dynamics model combining 3 indices used to project biomass under assumed future production • Decision tables for summarizing performance measures related to stock increase	• Decision table accepted as advice • Endorsed view that production likely to increase in 2003 to 2008 period, supported selection of harvest advice under assumption that 2003-2008 production is 1.25x that of 1996-2002 • Noted that annual data collection and stock assessment should mitigate risk to stock by allowing required adjustments to TAC	Decision table	3,000
2004 *2004/ 2005*	• 1992-2002 tag-recoveries, 2003 unusable • 1990-2003 index survey CPUE • 1990-2003 total catch • 1990-2003 "K" trap catch • 1990-2003 "K" trap logbook CPUE, nominal and standardized • Indicators from west coast Vancouver Island shrimp survey, IPHC survey, thornyhead survey, U.S. triennial survey, US stock assessments	• Evaluation of commercial trap, indexing survey, tag derived abundance indices • No age-structured population dynamics • New tagging model introduced that fits monthly population Apr-Nov and tag dynamics, and includes all years of tag recoveries • Simple biomass dynamics model combining 4 indices, used to project biomass and estimated annual production • Decision tables for summarizing performance measures related to stock increase	• Decision table accepted as advice • Supported the view that increased juvenile production was likely in keeping with evidence from various survey sources • Endorsed development of fishery objectives and decision rules • Agreed that changes in stock index values and patterns in observed data suggested that the B.C. stock was not a closed population and efforts should be made to exchange data with U.S. agencies	Decision table	*TBA*

APPENDIX E COMMERCIAL FISHERY DATA

E.1 COMMERCIAL FISHERY CATCH AND EFFORT DATA E-1
E.2 DATA SOURCES E-4
E.3 "OFFICIAL" LANDED WEIGHT E-6
E.4 RECONSTRUCTION OF LANDINGS HISTORY E-7
E.5 LITERATURE CITED E-8

E.1 Commercial fishery catch and effort data

This section provides an overview of commercial fishery catch and effort data over the recorded history of commercial sablefish (*Anoplopoma fimbria*) fishing. Nominal catch rate data are presented here and no attempt was made to standardize the underlying data for ancillary factors. Catches from research fishing at offshore locations are included in the landings summaries but are excluded from the catch rate (CPUE) calculations. Landings from seamounts, where identifiable, were excluded from the presentation. Landings data are current to July 31, 2003 for trawl fishing and to November 11, 2003 for trap and longline fishing. Sablefish catch and effort data from trap fishing are current to July 31, 2003.

The commercial fishery for sablefish has been active since the late nineteenth century and was described in detail by McFarlane and Beamish (1983). Total annual landings as high as 5,956 metric tons (t) were realized during the 1910s, however landings remained modest from 1920 to 1965, ranging between 209 t and 1,895 t (Figure E.1, panel A, Table E.1). Since 1969, total landings have ranged from 2,787 t (2002) to 7,408 t (1975) and have averaged 4,596 t.

Foreign fishery. Exploitation increased in the late 1960s with the arrival of foreign longline fleets from Japan, the US, the USSR and the Republic of Korea (McFarlane and Beamish 1983, Figure E.1, panel B, Table E.2). The largest annual landings of sablefish occurred during this period with a peak 7408 t removed in 1975. Unrestricted foreign fishing ceased in 1977 when the Canadian 200 mile Economic Exclusive Zone (EEZ) was declared. However, some foreign fishing was allowed between 1977 and 1980 to utilize yield surplus to Canadian domestic fleet needs.

Domestic fishery. Canadian landings since 1951 have been reported by longline, trawl, and trap gear (Table E.1, Table E.2). Since 1980, annual landings have averaged 4,343 t and ranged from 2,787 t in 2002 to 5402 t in 1988. The fishery has been managed under quotas allocated to the "K" licence (longline and trap gear) and "T" licence (trawl gear) fleets. Sablefish are caught incidentally in the halibut (*Hippoglossus stenolepis*) longline fishery, and there are small allocations to research charters and to First Nations food fisheries. Since 1977, the trawl components of the landings have always been the smallest, ranging from 3 to 16 percent of the total (Figure E.1, panel B, Table E.1). Since 1981, the trawl fishery has been allocated a fixed percentage (8.75) of the total allowable catch based on historic average trawl landings.

Longline was the dominant gear type in the directed sablefish fishery for most years until 1973. At this time, the trap fishery began to develop and the proportion of the catch taken by longline gear declined (Figure E.1, panel B, Table E.2). By 1978, trap gear clearly dominated domestic landings and the percentage of longline-caught fish in the total landings fluctuated between 6.3 percent (1979) and 28.0 percent (1990). The trap fishery landed an average of 449 t per year over the 1973 to 1978 period. Trap landings increased significantly in 1979, and beginning in 1980 have ranged from 1,975 t (2002) to 4,142 t (1993) with a mean of 3,336 t. In contrast, longline landings averaged 635 t per year over the 1980 to 2002 period.

IVQ fishery. During the period from 1990 to 1992, the first three years of Individual Vessel Quota (IVQ) management, the proportion of landings attributed to longline was high (17 to 28 percent) but then dropped to below 12 percent over the 1993 to 1998 period (Table E.2). The initial increase was due to large vessels that developed longline operations for other groundfish species that included sablefish caught under quota. In this way these vessels could fish most of the year. The subsequent decline in the proportion of longline landings was attributed to a move away from the multi-species longline approach in favor of dedicated trap fishing with transferable quota. The transferable quota allowed the vessels to fish sablefish most of the year and traps were chosen as the most efficient gear. An increase in the proportion of the catch taken by longline from 1999 through 2002 may reflect a move back to a multiple target species approach, i.e., so-called “combination fishing” where halibut “L” or rockfish (*Sebastes*) “Zn” licenses may be fished in conjunction with a sablefish “K” license to avoid discarding imposed by license regulation. The increase in longline landings could also reflect reduced availability of sablefish to trap gear during the 1999 through 2002 period (Kronlund et al. 2002).

Computation of nominal CPUE. Sablefish catch and effort data for the “K” licensed fishery are available from logbooks and skipper interviews beginning in 1979. These data are most comprehensive for the trap fishery. Annual trap landings (t) were determined by summing the “official catch” weight of retained sablefish in each calendar year. An explanation of “official catch” is provided in Section E.3. Catch per unit effort, U_t, in year *t* was computed using the sum of the individual catches, C_{ti}, divided by the sum of the associated effort, E_{ti}, for all records $i = 1, \ldots, n_t$ where both catch and effort data were available

(1) $$U_t = \frac{\sum_{i=1}^{n_t} C_{ti}}{\sum_{i=1}^{n_t} E_{ti}} \quad .$$

The proportion of total landings accounted for by logbook records with both catch and effort data ranged from 62 to 100 percent (Table E.3). Since effort was not reported for all sets over the 1979 to 2002 period, total annual effort cannot be computed by direct summation. Thus, total annual effort was estimated by dividing the total annual landings by the annual catch per unit effort

(2) $$\hat{E}_t = \frac{\sum_{i=1}^{m_t} C_{ti}}{U_t} \quad ,$$

where m_t is the number of set records in year *t* with landings data.

Catch, effort, and nominal CPUE: Figure E.2 shows the trap fishery landings and effort time series by calendar year and area from 1979 to 2002. The dashed line in each panel of the figure represents total annual trap landings (t). Vertical bars show the annual effort estimated using equation (2). Annual catch rates (kg/trap) computed using equation (1) are indicated by a solid line. The dotted vertical reference line indicates the introduction of mandatory escape rings in traps in 1999. Coast-wide catch rates were relatively stable from 1979 to 1987, but increased dramatically in 1988 and remained high for four years. Catch rates after 1991 declined to levels similar to, or slightly lower, than those observed prior to 1988. The coast-wide CPUE trends are largely driven by the catch rates in the north stock area, which has generally accounted for a larger proportion of both trap landings and effort. The CPUE trajectory is similar in the south stock area, although with less contrast between high and low levels.

The 1979 to 2001 period witnessed significant changes in the management regime for the sablefish fishery and in fishing practices. The introduction of IVQs in 1990 had a considerable impact on the distribution of trap effort. There was an abrupt shift in trap effort from the south (Major Areas 3 to 5) to the north (Major Areas 6 to 9) in 1991 as fishers under the IVQ program were attracted by higher catch rates and larger fish in the north (Figure E.1, Table E.3). The proportion of total trap catch taken from the north increased from an average of 0.57 from 1979 to 1990 to 0.87 in 1991 and 0.94 in 1992. In the late 1990s there was a shift back to the south and in 1998 landings from the south surpassed those from the north (Figure E.1, Table E.3). The shift can be attributed in part to declining CPUE in the north and in part to a management request to the industry to distribute effort coast-wide to avoid the complexity of implementing area-specific total allowable catches (TACs). Trap baiting practices have changed over the same period, with a shift from squid bait to a mixture of squid and Pacific hake (*Merluccius productus*) designed to improve trap efficiency. Escape rings were introduced by regulation in 1999, although some fishers experimented with escape rings in traps in 1998.

Fishery depth and seasonal distribution. Depth and seasonal differences in catch, effort and CPUE are shown in Figure E.3. The sablefish trap fishery extends from approximately 100 to 700 fm (180 to 1300 m) although approximately three quarters of the fishing effort is expended between 250 and 450 fm (460 to 825 m) (Figure E.3). The longline fishery generally occurs at shallower depths, with over three quarters of the fishing effort in less than 250 fm (460 m). Each panel of Figure E.3 is identical in construction to those presented in Figure E.1. The data were stratified by two periods (January to March, and April to December) and three depth strata (0 to 250 fm, 250 to 450 fm, and 450 fm and deeper) in addition to stock area. This stratification was used in previous analyses (eg. Saunders et al. 1996, Haist et al. 1997, 1999) because catch rates during the January to March period are generally higher than during other periods, and the January to March period has not been fished consistently over time. Historically, the 250 to 450 fm depth interval has represented the “core” depths fished by the commercial trap fleet. Note that the apparent absence of landings and effort values in some years where CPUE values are displayed is due to relatively small amounts of landings, and hence effort, that do not show on the scale chosen for the plots. Such occurrences represent minimal fishing activity.

The figure panels that correspond to April to December in the 250 to 450 fm depth stratum generally reflect the trends evident in aggregated data presented in Figure E.1, albeit with slightly less variability. Inspection of the panels confirms that this component of the data has represented the majority of fishing activity over time. However, the early 1990s showed an abrupt increase in trap fishing effort in the northern area in January to March. Since the mid 1990s, the proportion of trap effort in shallow depths (0 to 250 fm) has increased markedly, with the exception of the south stock area in the January to March period where the increase is small. These trends are particularly evident in the first half of 2003. There was no trap fishing after March and all the effort prior to that time was in the northern stock area. Furthermore, the majority of the effort has been at depths shallower than 250 fm.

For the trap fishery, the mean catch rates show high values in northern B.C. at the end and beginning of the calendar year, a pattern previously described by fishers. This effect is shown in Figure E.4, where catch rates were computed as the sum of the catch (kg) divided by the sum of the effort (traps fished) within blocks of latitude and month. Latitude intervals were defined by splitting the coast into 12 nautical mile strips from 48°N to 54.5°N. In some years, such as 1991 through 1993, the higher winter catch rates began to develop at the end of the calendar year in November and December. There is also a tendency for the higher catch rates to move in a southerly direction through the year. Northern catch rate intensity for December through March decreased in 1997 and 1998, increased in 1999, then declined over the years 2000 through 2001. Available data for the first three months of 2003 show catch rate intensities similar to those observed in 1991 through 1993.

E.2 Data Sources

Reconstructing historical catches and landings for sablefish involves collating data from multiple sources. The purpose of this section is to document the data sources, data characteristics and data selection criteria. Landings are defined as fish that are declared, or validated at dockside. Catch is defined as fish captured, which includes retained and discarded fish. Data are summarized by calendar year rather than by fishing year. As is usual for fisheries without complete at-sea observer coverage, enumeration of the discarded catch is problematic. The landings history is compared to previous summaries to document differences and provide rationale for the data selection choices used here.

McFarlane and Beamish (1983): 1913 to 1981

Sablefish landings data for the period from 1913 to 1981 were collated and summarized by McFarlane and Beamish (1983). Their Tables 1 through 4 were adopted as accepted landings figures for years not covered by the database sources outlined below. Landings were not separated by gear type until 1951, and a portion of the landings prior to 1951 may have been caught outside Canadian waters. In 1951, an increase in the resolution of data collection made it possible to distinguish fish caught outside of Canadian waters. Foreign catches were not separated by gear type and there is little information on USSR catches prior to 1973.

GFCatch: 1954 to 1994

The GFCatch database is maintained by DFO at the Pacific Biological Station in Nanaimo, British Columbia on a SQL Server platform (http://pacpbsgfiis/sql/). This database holds commercial groundfish catch and effort data recorded from 1954 to 1995. Fisher or observer logbooks, fisher interviews, offload observations, and landing records were reconciled to provide a "best" estimate of catch and effort for each fishing event. A fishing event is a single set or a group of sets within a common area. A landing record was either a sales slip or Dockside Monitoring Program (DMP) validation record. Sales slips are mandatory records produced by the fish buyers that indicate species, product, weight, landing date, vessel and some estimates of the area of capture and effort. Validation records obtained from the DMP were essentially more detailed and accurate sales slips with weights of fish unloaded independently observed at the dock. Details concerning the content, data sources, structure, and data processing can be found in Rutherford (1999). Species catch weights for each fishing event are qualified by a utilization code that indicates the fate of the fish. Landings were defined to be all fates except "Discarded" and "Dumped".

Trawl

GFCatch holds groundfish trawl trips from 1954 to 1995. From 1954 to 1990, multiple tows in a management area were aggregated into a single fishing event. Submission of the logbook was voluntary, few discard data were recorded, and there was poor identification of similar species such as the rockfishes (*Sebastes*). In 1987, logbook submission became mandatory in the trawl fleet. In 1991 tow-by-tow records were entered, followed by the addition of geographic co-ordinates in 1994. The submission of detailed logbook information including geographic positions became mandatory in 1994. Data obtained from a few at-sea observer trips was also entered into GFCatch in place of the associated fisher logbooks. Trawl landings records are primarily sales slips, but may be augmented by observed landings. Dockside monitoring became mandatory for most landings in 1994 (Strait of Georgia and West Coast of Vancouver Island hake were excluded) and all landings in 1995.

Trap

GFCatch holds sablefish trap fishing trips from 1979 to 1995. From 1979 to 1989, logbook submission was voluntary and multiple sets in an area were combined into single events. In 1990 logbook submission became mandatory and set-by-set data were recorded and entered into the database. From 1979 to 1989, landing records were primarily sales slips and in 1990 mandatory dockside monitoring was implemented to provide independently validated landings.

Longline

GFCatch holds most longline (both directed sablefish and other) data from 1979 to 1986, with multiple sets in an area grouped into a single fishing event. Landings records were primarily sales slips. Data entry ceased in 1986 due to staffing reductions.

PacHarvTrawl (http://pacpbsgfiis/sql/)

Trawl catch and effort data from 1996 until the present is maintained by DFO at the Pacific Biological Station, Nanaimo, B.C. The PacHarvTrawl database runs on a SQL Server platform. For each trip, the database contains dockside monitoring program (DMP) validation records as well as detailed tow-by-tow records from fisher or observer logbooks. The logbook and DMP data are linked so it is possible to create an "official" catch based on a comparison of the logbook catch estimates to the actual weight of fish landed. Observer coverage is 100 percent for trawl fishing that intercepts sablefish, thus there are detailed records of estimated discards.

PacHarvHL (http://pacpbsgfiis/sql/)

Longline catch and effort data from the "Zn" rockfish and halibut fishery from 1991 to the present are maintained by DFO at the Pacific Biological Station, Nanaimo, B.C. The database is called PacHarvHL and runs on a SQL Server platform. For the Zn fishery, each trip has dockside validation records as well as set-by-set logbook records. Both observer and fisher logs are entered for the Zn fishery so there is the potential for catch duplication during a query. The "L" halibut fishery data are limited to observer logs and dockside validation data; fisher logbooks are maintained by the International Pacific Halibut Commission (IPHC) and are not available. Observer logbook records contain significant amounts of retained sablefish, yet there is very little landed sablefish. This discrepancy is due to the fact that longline vessels typically fish combination trips and land sablefish under a "K" license. The landings records for the retained sablefish that occur in the PacHarvHL logbook data can be found in PacHarvSable where "K" fishery validation data are stored.

PacHarvSable (http://pacpbsgfiis/sql/)

PacHarvSable is a recently constructed database running on a SQL Server platform and maintained by DFO at the Pacific Biological Station in Nanaimo, B.C. PacHarvSable holds detailed set-by-set fishing records for trap and longline fisher logbook data for the K fishery (directed sablefish) from 1990 to the present. Validated landings from the DMP are available from 1995 to the present. Longline fisher logbook records are also stored in PacHarvSable for the period 1987 to 1989. Fisher logs and validation records are linked, so that "official" catch can be extracted based on comparison of the logbook catch estimates to the actual weight of fish landed.

PacHarv3.0

PacHarv3.0 is an ORACLE-based database that holds sales slip data from 1982 to the present. The DFO Catch Statistics Unit in Vancouver, B.C. maintains the database. Sablefish sales slip records are drawn from longline, trap, trawl, troll and handline gear types.

E.3 "Official" Landed Weight

The "official" landed weight per set is calculated as follows:

1. From the fisher or observer logs, sum the total weight of each species caught and retained per trip and then calculate the proportion of this total caught in each set;
2. Multiply the proportions from Step 1 by the validated landed round weight of each species recorded at dockside, i.e., the landed weight is considered the true weight;
3. Assign species recorded at dockside, but not recorded by the fisher, to a dummy set number 999;
4. Species recorded by the fisher as discarded at sea are given a landed weight of 0.

E.4 Reconstruction of Landings History

Data sources. For historical data from 1913 to 1950, and foreign landings from 1964 to 1981, Tables 1 and 4 in McFarlane and Beamish (1983) were adopted. For trawl landings from 1951 to 1953, Tables 2 and 3 from McFarlane and Beamish (1983) were used. From 1954 to 1995, trawl landings were selected from GFCatch, and from 1996 to the present, PacHarvTrawl was the data source. For trap landings from 1951 to 1978, Tables 2 and 3 from McFarlane and Beamish (1983) were used. For trap landings from 1979 to 1995 the data were drawn from GFCatch, and from 1996 to the present, PacHarvSable data were selected. Tables 2 and 3 in McFarlane and Beamish (1983) were used for longline landings from 1951 to 1978. GFCatch was the source of longline landings from 1979 to 1986, and from 1987 to 1994, PacHarv3.0 was used. Longline landings from 1995 to the present are selected from PacHarvSable. For other gear types, the 1951 to 1981 data are drawn from Tables 2 and 3 in McFarlane and Beamish (1983), while data from 1982 onwards were obtained from PacHarv3.0. Data sources are summarized in the following table:

Period	Trawl	Trap	Longline	Other	Foreign
1913 – 1950	Table 1	Table 1	Table 1	Table 1	
1951 – 1953	Table 2,3	Table 2,3	Table 2,3	Table 2,3	
1954 – 1963	GFCatch	Table 2,3	Table 2,3	Table 2,3	
1964 – 1978	GFCatch	Table 2,3	Table 2,3	Table 2,3	Table 4
1979 – 1981	GFCatch	GFCatch	GFCatch	Table 2,3	Table 4
1982 – 1986	GFCatch	GFCatch	GFCatch	PacHarv3	
1987 – 1994	GFCatch	GFCatch	PacHarv3	PacHarv3	
1995	GFCatch	PacHarvSable	PacHarvSable	PacHarv3	
1996-present	PacHarvTrawl	PacHarvSable	PacHarvSable	PacHarv3	

Differences from previous assessment documents. There are numerous differences between the landings data presented in this document and assessments prior to 2002 (e.g., Table 1 in Haist et al. 2001). Of those, 69 differ by less than 1 t and were ignored. Table E.4 lists differences that are greater than 1 t. The differences reflect new data, auditing and correcting of historical data, and new electronic data retrieval capability for some data sources. Table E.5 lists differences between the landings data presented in this document and the assessments in 2002 and 2003 (Kronlund et al. 2002, Kronlund et al. 2003). The fishing event date was used in this presentation, whereas in 2002 and 2003 only the landing date was used. If a fishing trip includes January 1, a fishing event may occur in one year while the landing occurs in the following year.

This shift explains all the differences between the current summaries and the 2002 and 2003 data.

E.5 Literature Cited

Haist, V., Saunders, M.W., Hilborn, R., and M. Maunder. 1997. Sablefish stock assessment for 1997 and recommended yield options for 1998. Can. Stock Assess. Sec. Res. Doc. 97/146.

Haist, V., Fournier, D., and M.W. Saunders. 1999. Reconstruction of B.C. sablefish stocks, 1966-1998, and catch projections for 1999, using an integrated catch-age mark-recapture model with area and depth movement. Can. Stock Assess. Sec. Res. Doc. 99/79.

Haist, V., Hilborn, R., and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. Can. Sci. Advisory Res. Doc. 2001/135. 54 p.

Kronlund, A.R., M. Wyeth, and R. Hilborn. 2002. Review of survey, commercial fishery, and tagging data for sablefish (*Anoplopoma fimbria*) in British Columbia: Supplement to the November 2001 sablefish stock assessment. Can. Sci. Adv. Sec. Res. Doc. 2002/074. 109 p.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

McFarlane, G.A. and R.J. Beamish. 1983. Overview of the fishery and management strategy for sablefish (*Anoplopoma fimbria*) in waters off the west coast of Canada. p. 13-35. *In* Proceedings of the Second Lowell Wakefield Fisheries Symposium, Anchorage, AK. Alaska Sea Grant Report 83-3.

Rutherford, K.L. 1999. A brief history of GFCATCH (1954-1995), the groundfish catch and effort database at the Pacific Biological Station. Can. Tech. Rep. Fish. Aquat. Sci. 2299: 66 p.

Saunders, M.W., Leaman, B.M., Haist, V., Hilborn, R., and G.A. McFarlane. 1996. Sablefish stock assessment for 1996 and recommended yield options for 1997. PSARC Working Paper G96-5.

Table E.1 Annual sablefish landings (t) in Canadian waters by gear type, excluding sablefish landed from seamounts. Data for 2003 are preliminary.

Year	Trawl	Trap	Longline	Other	Canadian	Foreign	Total
1913					1,988		1,988
1914					3,209		3,209
1915					2,441		2,441
1916					4,312		4,312
1917					5,956		5,956
1918					2,039		2,039
1919					716		716
1920					1,754		1,754
1921					1,383		1,383
1922					1,293		1,293
1923					1,135		1,135
1924					1,238		1,238
1925					1,017		1,017
1926					705		705
1927					1,118		1,118
1928					911		911
1929					1,042		1,042
1930					1,124		1,124
1931					397		397
1932					436		436
1933					413		413
1934					435		435
1935					659		659
1936					490		490
1937					912		912
1938					576		576
1939					617		617
1940					948		948
1941					1,188		1,188
1942					835		835
1943					1,426		1,426
1944					1,519		1,519
1945					1,428		1,428
1946					1,619		1,619
1947					905		905
1948					1,483		1,483
1949					1,895		1,895
1950					648		648
1951	23.10		772.80	0.50			796.40
1952	34.00		453.20	0.60			487.80
1953	8.00		335.60	1.10			344.70
1954	26.41	0.30	432.30				459.01
1955	15.21		359.00				374.21
1956	36.47		172.80				209.27
1957	50.97	0.30	465.60				516.87
1958	117.59	0.60	167.10				285.29
1959	88.17		298.30				386.47
1960	65.49		423.30				488.79
1961	97.89		321.30				419.19
1962	113.72		277.70	1.10			392.52

Year	Trawl	Trap	Longline	Other	Canadian	Foreign	Total
1963	64.81		222.30	0.20			287.31
1964	125.15		274.50	0.10		83	482.75
1965	261.91		193.20	0.30		92	547.41
1966	311.90		325.70	0.20		269	906.80
1967	138.56		252.90	0.10		1,254	1,645.56
1968	167.02		292.30	15.10		2,455	2,929.42
1969	148.25		162.30	0.60		4,763	5,074.15
1970	165.86		142.10	0.50		5,246	5,554.46
1971	189.31		123.00			3,211	3,523.31
1972	688.30		399.70			4,818	5,906.00
1973	82.79	745.80	119.80			3,038	3,986.39
1974	121.77	327.10	41.30	1.80		4,287	4,778.97
1975	279.78	469.40	152.20	0.90		6,506	7,408.28
1976	382.04	303.40	89.40	0.10		6,302	7,076.94
1977	786.53	214.60	77.10	6.80		3,718	4,803.03
1978	130.54	634.60	57.20	7.80		3,051	3,881.14
1979	276.05	1,480.12	276.85	6.00		2,348	4,387.02
1980	335.32	3,210.77	248.63				3,794.72
1981	228.77	3,275.33	326.13				3,830.23
1982	245.89	3,437.84	343.65	0.27			4,027.65
1983	274.06	3,610.52	451.41	10.52			4,346.52
1984	187.00	3,275.39	365.05				3,827.44
1985	233.14	3,501.27	458.31				4,192.71
1986	551.83	3,277.08	619.16	0.78			4,448.84
1987	406.93	2,954.29	1,268.57	0.68			4,630.46
1988	637.27	3,488.50	1,273.59	3.22			5,402.58
1989	623.38	3,772.04	928.60	0.02			5,324.03
1990	460.72	3,072.39	1,371.81				4,904.93
1991	438.82	3,494.43	1,179.16				5,112.40
1992	448.65	3,710.23	847.50	1.11			5,007.49
1993	543.08	4,142.38	424.24	0.06			5,109.77
1994	483.14	4,050.72	467.69				5,001.54
1995	427.42	3,272.24	474.34	4.76			4,178.77
1996	192.46	2,999.40	278.67				3,470.52
1997	156.29	3,555.12	430.64				4,142.06
1998	376.07	3,771.98	443.65				4,591.71
1999	403.04	3,682.90	628.07	3.61			4,717.62
2000	326.28	2,758.12	749.12	0.00			3,833.52
2001	299.60	2,431.50	484.31				3,215.41
2002	266.81	1,975.02	542.74	2.37			2,786.94
2003	*112.32*	*808.73*	*534.30*				*1,455.35*

Table E.2 Percent of annual sablefish landings (metric tonnes) by gear type, excluding sablefish landed from seamounts. Data for 2003 are preliminary.

Year	Trawl	Trap	Longline	Other	Canadian	Foreign	Total Landings (t)
1913					100		1,988
1914					100		3,209
1915					100		2,441
1916					100		4,312
1917					100		5,956
1918					100		2,039
1919					100		716
1920					100		1,754
1921					100		1,383
1922					100		1,293
1923					100		1,135
1924					100		1,238
1925					100		1,017
1926					100		705
1927					100		1,118
1928					100		911
1929					100		1,042
1930					100		1,124
1931					100		397
1932					100		436
1933					100		413
1934					100		435
1935					100		659
1936					100		490
1937					100		912
1938					100		576
1939					100		617
1940					100		948
1941					100		1,188
1942					100		835
1943					100		1,426
1944					100		1,519
1945					100		1,428
1946					100		1,619
1947					100		905
1948					100		1,483
1949					100		1,895
1950					100		648
1951	3		97	0	100		796.40
1952	7		93	0	100		487.80
1953	2		97	0	100		344.70
1954	6	0	94		100		459.01
1955	4		96		100		374.21
1956	17		83		100		209.27
1957	10	0	90		100		516.87
1958	41	0	59		100		285.29
1959	23		77		100		386.47
1960	13		87		100		488.79
1961	23		77		100		419.19
1962	29		71	0	100		392.52

Year	Trawl	Trap	Longline	Other	Canadian	Foreign	Total Landings (t)
1963	23		77	0	100		287.31
1964	26		57	0	83	17	482.75
1965	48		35	0	83	17	547.41
1966	34		36	0	70	30	906.80
1967	8		15	0	24	76	1,645.56
1968	6		10	1	16	84	2,929.42
1969	3		3	0	6	94	5,074.15
1970	3		3	0	6	94	5,554.46
1971	5		3		9	91	3,523.31
1972	12		7		18	82	5,906.00
1973	2	19	3		24	76	3,986.39
1974	3	7	1	0	10	90	4,778.97
1975	4	6	2	0	12	88	7,408.28
1976	5	4	1	0	11	89	7,076.94
1977	16	4	2	0	23	77	4,803.03
1978	3	16	1	0	21	79	3,881.14
1979	6	34	6	0	46	54	4,387.02
1980	9	85	7		100		3,794.72
1981	6	86	9		100		3,830.23
1982	6	85	9	0	100		4,027.65
1983	6	83	10	0	100		4,346.52
1984	5	86	10		100		3,827.44
1985	6	84	11		100		4,192.71
1986	12	74	14	0	100		4,448.84
1987	9	64	27	0	100		4,630.46
1988	12	65	24	0	100		5,402.58
1989	12	71	17	0	100		5,324.03
1990	9	63	28		100		4,904.93
1991	9	68	23		100		5,112.40
1992	9	74	17	0	100		5,007.49
1993	11	81	8	0	100		5,109.77
1994	10	81	9		100		5,001.54
1995	10	78	11	0	100		4,178.77
1996	6	86	8		100		3,470.52
1997	4	86	10		100		4,142.06
1998	8	82	10		100		4,591.71
1999	9	78	13	0	100		4,717.62
2000	9	72	20	0	100		3,833.52
2001	9	76	15		100		3,215.41
2002	10	71	19	0	100		2,786.94
2003	*8*	*56*	*37*		*100*		*1,455.35*

Table E.3 Distribution of annual trap landings by area, and the percentage of landings with associated effort data by area.

	Percent of trap landings			Percent of landings with effort data		
Year	**South**	**North**	**Unknown**	**South**	**North**	**Coast**
1973	47	53	0	0	0	0
1974	49	51	0	0	0	0
1975	9	91	0	0	0	0
1976	16	84	0	0	0	0
1977	32	68	0	0	0	0
1978	38	62	0	0	0	0
1979	33	67	0	40	41	41
1980	63	37	0	74	96	83
1981	36	64	0	88	91	90
1982	40	60	0	71	79	76
1983	34	66	0	76	84	81
1984	46	54	0	75	89	82
1985	54	46	0	73	90	81
1986	40	60	0	76	86	81
1987	51	49	0	55	69	62
1988	37	63	0	100	97	98
1989	46	54	0	94	81	87
1990	42	58	0	98	100	99
1991	13	87	0	100	100	100
1992	6	94	0	70	92	91
1993	27	73	0	91	90	90
1994	31	69	0	74	99	91
1995	37	62	1	57	81	73
1996	33	67	0	100	94	96
1997	38	62	0	98	100	99
1998	55	45	0	99	100	99
1999	31	69	0	100	100	100
2000	23	77	0	100	99	99
2001	43	57	0	100	100	100
2002	31	68	1	98	97	97
2003	*0*	*89*	*11*		*89*	*89*

Table E.4 Differences in landings history between this document and previous summaries published prior to 2002.

Year	Column	New	Old	Difference	Reason for difference
1957	trawl	50.97	47.10	3.87	likely due to addition of data to GFCatch
1959	trawl	88.17	57.30	30.87	likely due to addition of data to GFCatch
1966	trawl	311.90	309.70	2.20	likely due to addition of data to GFCatch
1968	trawl	167.02	156.00	11.02	likely due to addition of data to GFCatch
1970	trawl	165.86	116.50	49.36	likely due to addition of data to GFCatch
1973	foreign	3,038.00	3,032.00	6.00	USSR catch was not included
1976	trawl	382.04	379.00	3.04	likely due to addition of data to GFCatch
1982	other	0.3	18.4	-18.13	
1983	other	10.52	15.4	-4.88	
1983	trap	3,610.52	3,678.00	-67.48	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1987	other	0.68	56.10	-55.42	
1987	longline	1,268.57	1,133.40	135.17	
1988	trawl	637.27	638.60	-1.33	old data included some sablefish captured on seamounts
1988	trap	3,488.50	3,509.70	-21.20	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1988	longline	1,273.59	1,194.30	79.29	
1989	trap	3,772.04	3,828.30	-56.26	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1990	trap	3,072.39	3,162.10	-89.71	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1991	trap	3,494.43	3,582.00	-87.57	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1991	longline	1,179.16	1,089.20	89.96	
1992	trap	3,710.23	3,789.20	-78.97	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1992	longline	847.50	889.10	-41.60	
1993	trap	4,142.38	4,168.40	-26.02	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included

Year	Column	New	Old	Difference	Reason for difference
1993	other	0.06	4.30	-4.24	
1993	longline	424.24	371.60	52.64	
1994	trap	4,050.72	4,090.60	-39.88	old data only excluded sablefish captured on Bowie, Brown Bear, Pratt, and Surveyor Seamounts while other seamounts were included
1994	longline	467.69	511.00	-43.31	
1995	longline	474.3	281.7	192.6	
1995	trap	3,272.3	3,319.0	-46.7	if we use PacHarvSable
1995	trap	3,321.93	3,319.00	2.93	if we use GFCatch, likely due to addition of data
1995	trawl	427.42	406.50	20.92	likely due to addition of data to GFCatch
1996	trawl	192.46	211.00	-18.54	
1996	trap	2,999.40	2,914.4	85.0	
1996	longline	278.67	253.6	25.07	
1997	trawl	156.29	285.00	-128.71	
1997	trap	3,555.12	3,480.2	74.92	
1997	longline	430.64	412.8	17.84	
1998	trawl	376.07	328.00	48.07	possibly new data added to PacHarvTrawl
1998	longline	443.65	445.9	-2.25	
1998	trap	3,771.98	3,718.1	53.88	
1999	trawl	403.04	399.60	3.44	possibly new data added to PacHarvTrawl
1999	longline	628.07	608.1	19.97	
1999	trap	3,682.90	3,709.4	-26.5	
2000	trap	2758.12	2729.6	28.52	
2000	longline	749.12	750.50	-1.38	

Table E.5 Differences in landings history between this document and the summaries presented in 2002 and 2003.

Year	Gear	New	Old	Difference	Reason for difference
1996	trawl	192.46	190.82	1.63	Preferential use of fishing event date over offload date
1997	trawl	156.29	157.34	-1.05	Preferential use of fishing event date over offload date
1999	trap	3,682.90	3,665.71	17.19	Preferential use of fishing event date over offload date
2000	trap	2,758.12	2,727.47	30.65	Preferential use of fishing event date over offload date
2000	longline	749.12	750.34	-1.21	Preferential use of fishing event date over offload date
2001	trawl	299.60	298.03	1.57	Preferential use of fishing event date over offload date
2001	trap	2,431.50	2,476.62	-45.12	Preferential use of fishing event date over offload date
2001	longline	484.31	485.95	-1.65	Preferential use of fishing event date over offload date
2002	trawl	266.81	64.95	201.86	Complete year of data and the preferential use of the fishing event date over the offload date
2002	trap	1,975.02	1,042.23	932.79	Complete year of data and the preferential use of the fishing event date over the offload date
2002	longline	542.74	317.46	225.28	Complete year of data and the preferential use of the fishing event date over the offload date

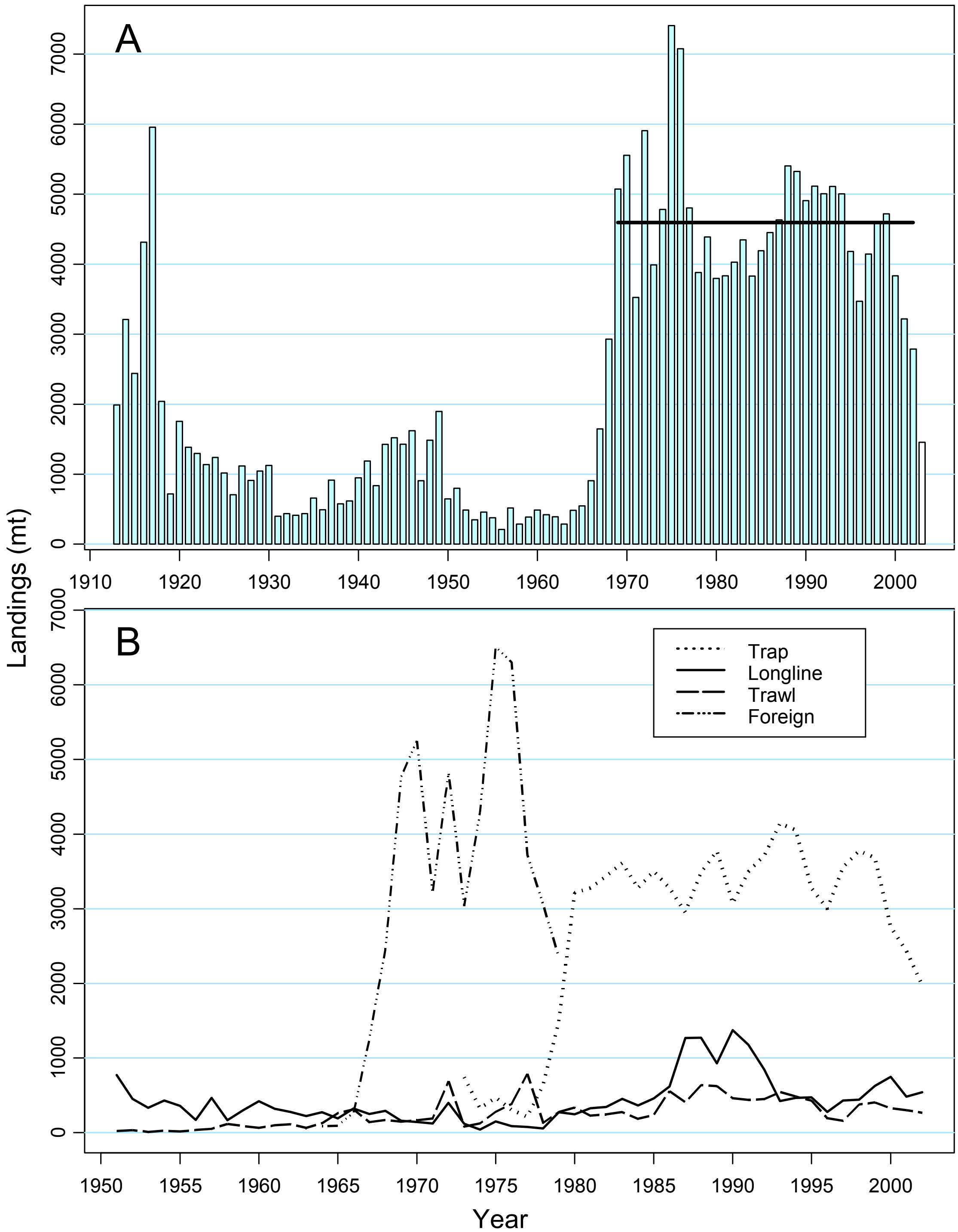


Figure E.1 Annual sablefish landings (t) from 1913 to 2003 from all sources (Panel A). The thick horizontal line is the mean of annual landings from 1969 to 2002. Panel B shows annual landings by gear type for the period 1951 to 2003.

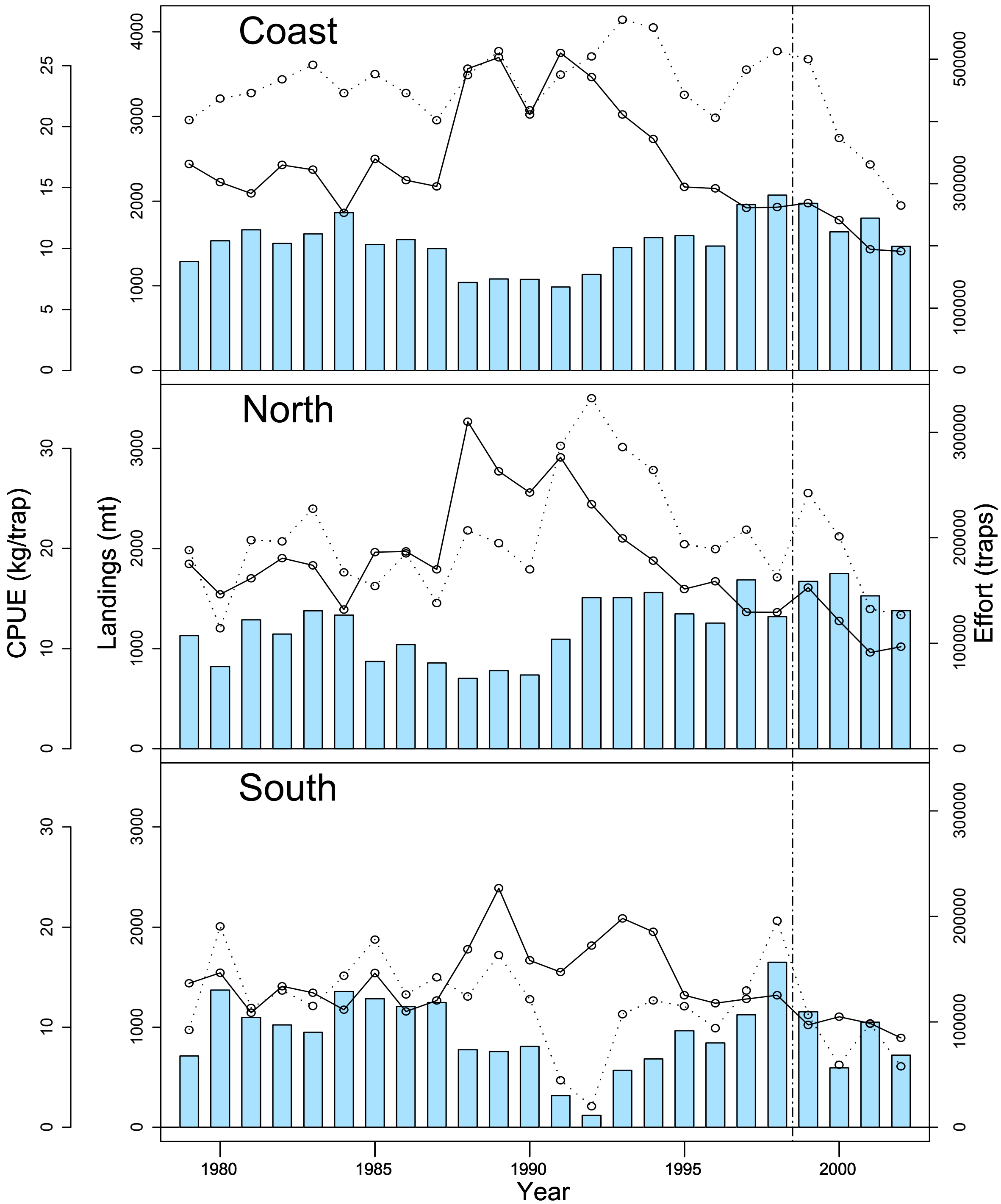


Figure E.2 Annual trap fishery landings (metric tonnes, dotted line), CPUE (kg/trap, solid line), and estimated effort (traps, vertical bars) by coast-wide, north, and south stock areas. The vertical dot-dash line indicates the inception of mandatory escape rings in the commercial trap fishery.

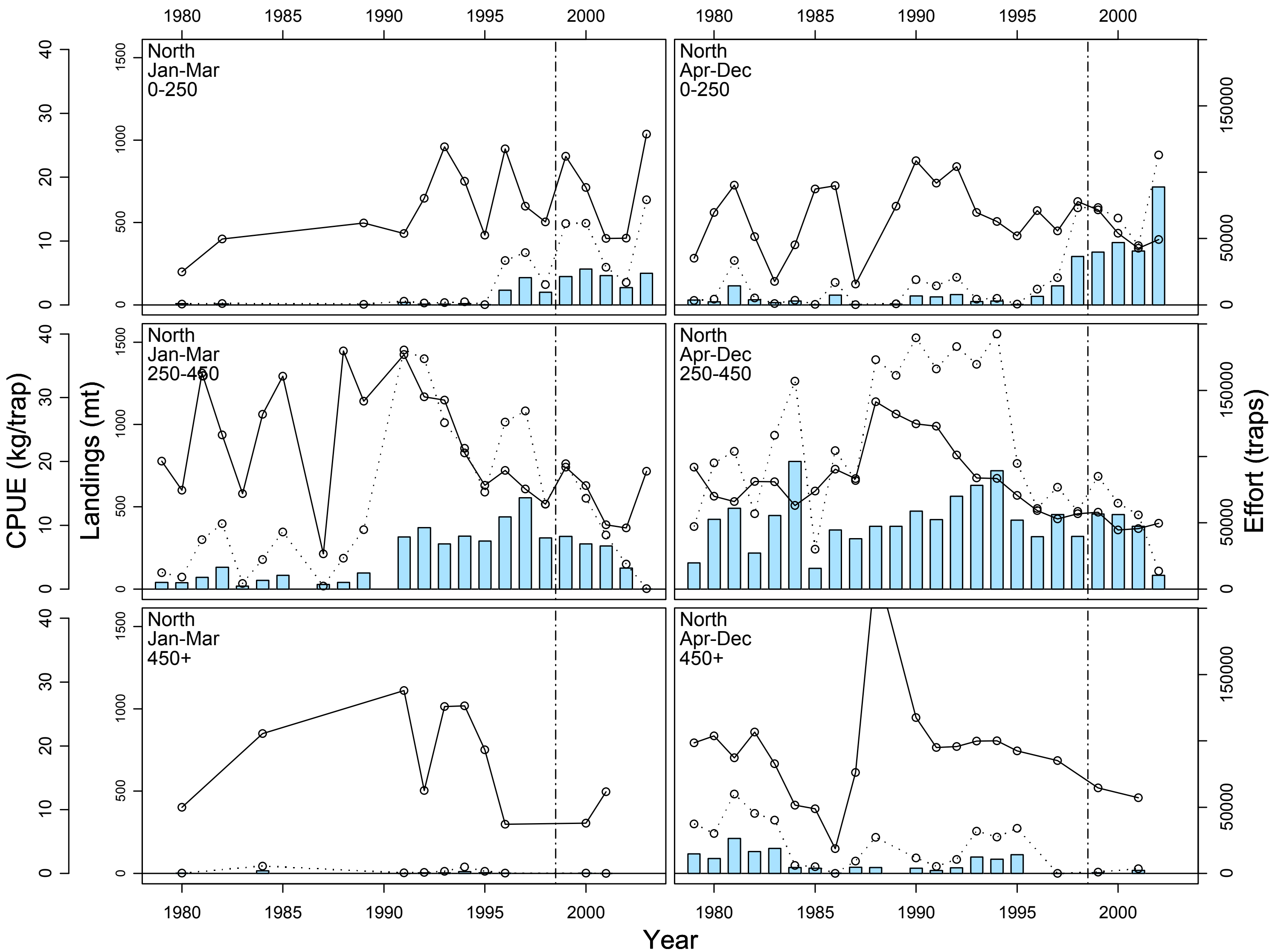


Figure E.3 Annual trap fishery landings (metric tonnes, dotted line), CPUE (kg/trap, solid line), and estimated effort (traps, vertical bars) by area, season, and depth stratum (fm).

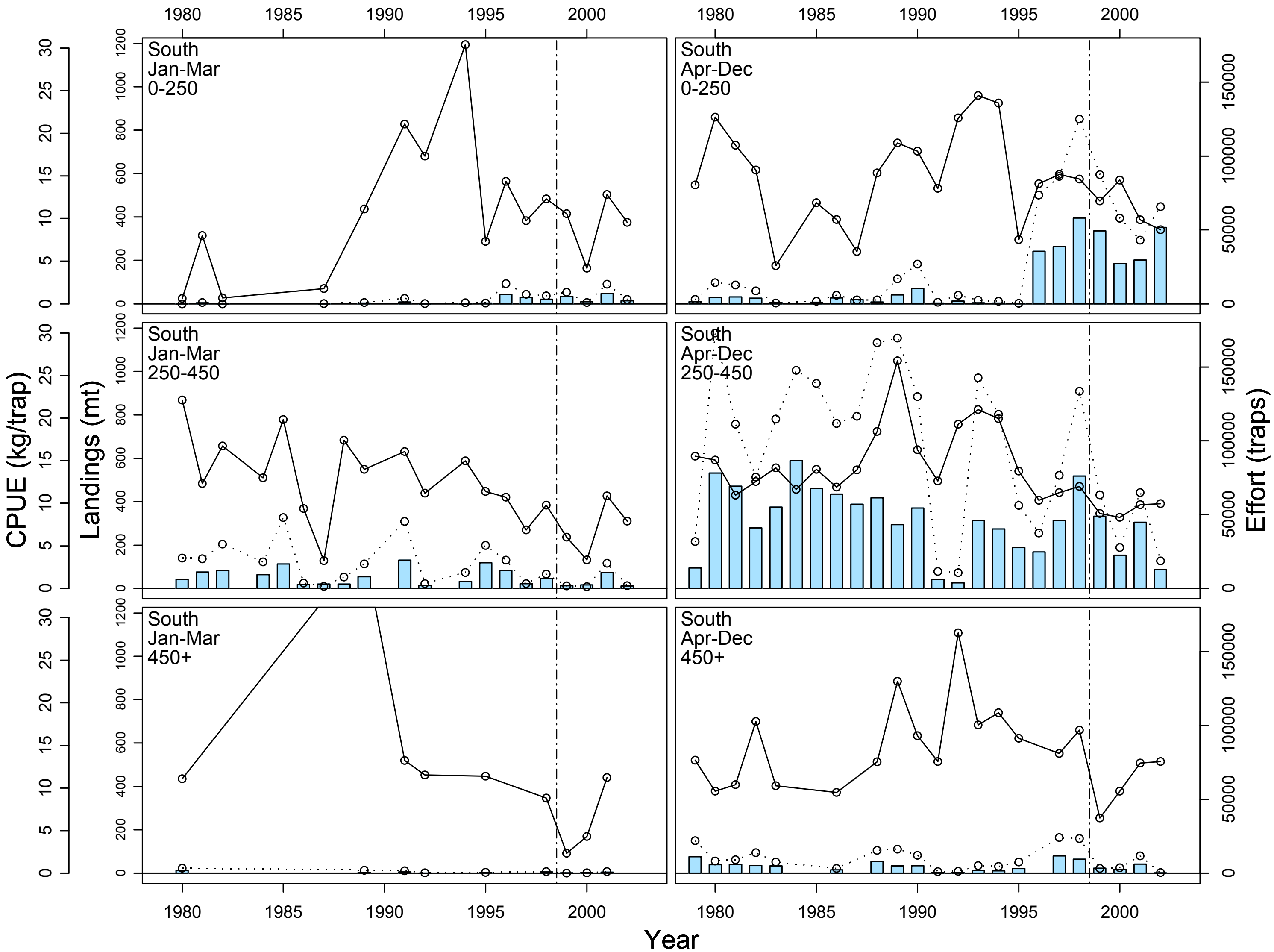


Figure E.3 continued.

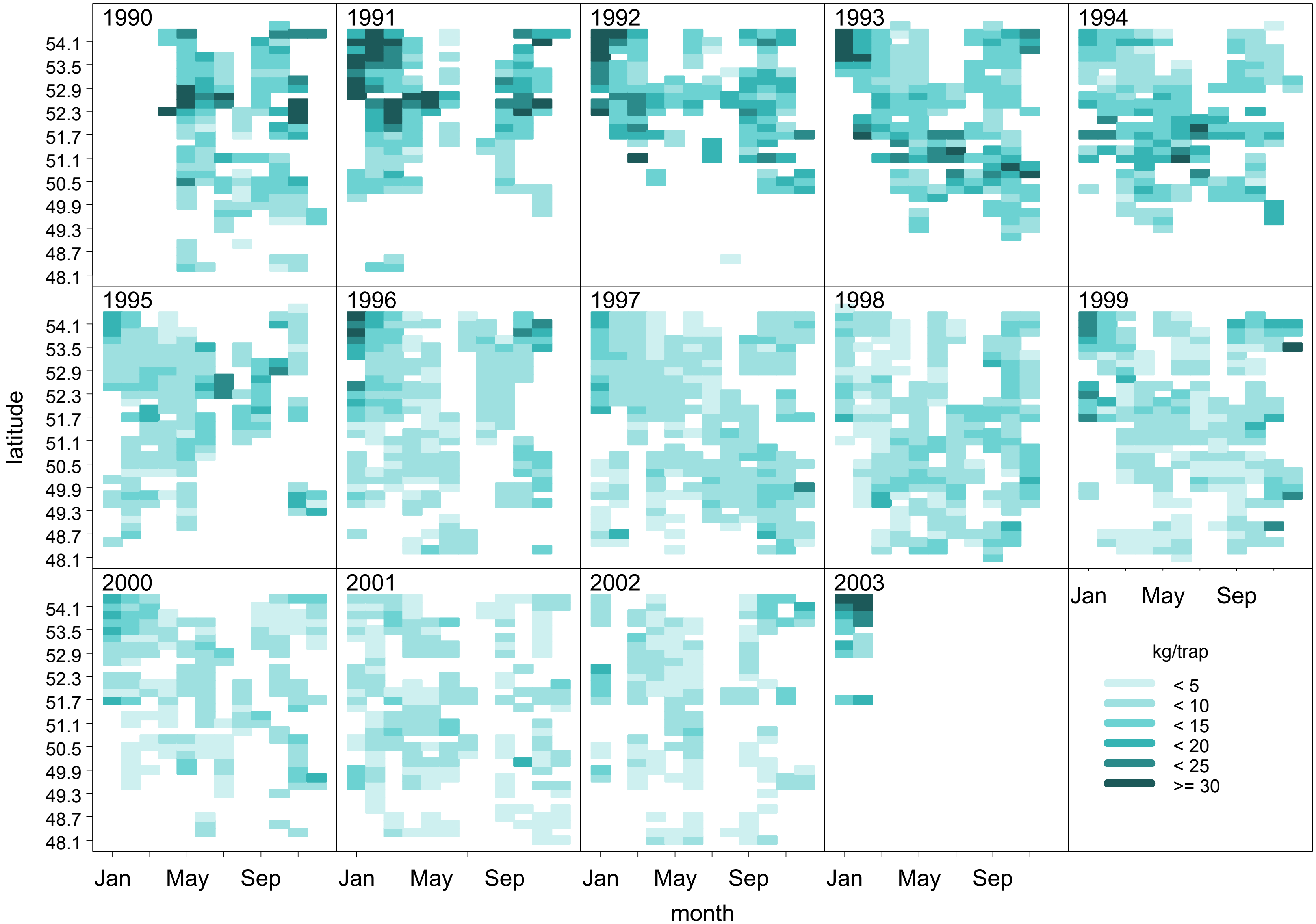


Figure E.4 Sablefish trap CPUE (kg/trap) by latitude, month and year. The intensity of the shading is proportional to CPUE for each block of latitude and month.

APPENDIX F ANALYSIS OF COMMERCIAL CATCH RATES

F.1 INTRODUCTION F-1
F.2 GENERALIZED LINEAR MODEL STANDARDIZATION OF CPUE F-1
F.3 MODEL RESULTS F-2
F.4 LITERATURE CITED F-2

F.1 Introduction

Analyses to standardize fishery catch rate (CPUE) data, using generalized linear modeling methods (GLM), were first conducted for the 2002 sablefish stock assessment (section 4 of Kronlund et al. 2003). The annual trap fishery catch rate index from this analysis was one of three indices used in a biomass dynamics model. Annual indices resulting from a standardization analysis of the longline fishery data were not believed to reflect changes in stock abundance, so the longline catch rate data analysis is not updated here. The trap-fishery GLM analyses were updated using data through July 2003. In practice, trap fishing occurred only in January through February 2003 and only in northern B.C. Thus, small amounts of additional data are available. The methodology used for the 2003 CPUE standardization is the same as that used for the 2002 assessment, and only a cursory description of methodology and results is presented here.

Sablefish logbook data, which contain information from individual trap sets, were extracted from the PacHarvSable database for 1990 to 2003. Collection of logbook data began earlier than 1990, but these data were aggregated over fishing events (Appendix E). Initially a voluntary program, the completion of logbook records when fishing under a "K" license became mandatory in 1990 (Appendix C). A data selection and grooming process was undertaken with two objectives: (1) to limit the data set to coastal offshore fishing events (i.e., remove inshore and seamount fishing records), and (2) to remove records that were likely to contain erroneous information. The criteria used in the data grooming process and the number of logbook records that were selected are summarized in Table F.1.

F.2 Generalized linear model standardization of CPUE

For the 2002 CPUE standardization, a core set of fishing masters was selected for inclusion in the analysis. The selection was based on fishing master rather than fishing vessel because experience is more likely to be associated with fishing success in this fishery. A minimum of five years of documented fishing effort was the basis for selecting fishing masters, and the same set selected for the 2002 analysis was used in the current analysis.

The same log-normal linear model used for the 2002 CPUE standardization is used this year. Because the quantity of new data is small, no effort was made to re-do the stepwise analysis to evaluate alternative covariates. Rather, the set of covariates selected in the 2002 analysis was used again this year. The dependent variable was the natural logarithm of catch rate, with catch rate measured as kilograms per trap. Independent variables that were treated as factors were *year*, *region* (northern BC, southern BC), *fishing master* and *minor area*. *Day-of-year* entered the model as a polynomial of degree 3. Note that a *year:region* interaction term was included in the model with the main effects (e.g., *year*region*), independent of statistical significance. An additional model was fit that excluded the *region* covariate, strictly for use in the biomass dynamics model.

F.3 Model results

Model results, in terms of the proportion of the total deviance explained, are shown in Table F.2. The first variable to enter the model was *fishing master* followed by *day of year* and *minor area*. Second order interactions involving *fishing master* were not evaluated because they would greatly increase the number of terms in the model. Inclusion of a *day of year:minor area* interaction did provide a fair improvement in the model fit, although the final model accounted for only 28 percent of the variance in the log CPUE (Table F.2). The sequence in which model covariates entered the model that did not include the *region* covariate was the same as for the model where it was included. Results for the model without the *region* covariate are presented in Table F.3.

The *year* effects estimated by the standardized CPUE model are shown in Figure F.1 for the northern region, southern region, and the entire coast. Also shown on the figure panels are the nominal CPUE estimates (Appendix E). There is very close agreement between the standardized and nominal CPUE indices. The vertical grey bars in Figure F.1, drawn between 1998 and 1999, demarcate the introduction of mandatory escape rings in the trap fishery. The use of escape rings is likely to decrease catch rates relative to the period prior to their use, thus creating two time series that are likely not comparable.

For the northern B.C. coast, the CPUE *year* effects show a continuous decline from 1991 through 1998. The magnitude of the southern region *year* effects in the early 1990s were not as large as those for the northern region, and the major decline in CPUE occurred between 1994 and 1995. It is not valid to compare *year* effects across 1998 because of the introduction of escape-rings. For the southern B.C. region, the *year* effects are relatively stable between 1999 and 2002, and there is no update for 2003. The CPUE index for northern B.C. decreased from 1999 through 2001, and has increased significantly in 2003. The CPUE trends estimated for coast wide data tend to be intermediate between the northern and southern B.C. values.

F.4 Literature Cited

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

Table F.1 Data selection criteria and the number of records selected for the standardized CPUE analysis.

Reason	**Records excluded for the following reasons:**	**No. of records after selection criteria:**
Year	- Remove 5 records w/o year information	47405
Location information	- Fishing locations in Hecate Strait, Strait of Georgia, or Johnson Strait - Fishing locations at Seamounts - Latitude is < 40 degrees or longitude is < 120 degrees, or minutes is > 60	42614
Research sets	- Purpose code was "research"	41329
Other	- Start or end bottom depth are < 5 m - The number of traps set is > 0 and < 500	40858
Core skippers	- Not one of the 19 core skippers	34211
Catch	- Remove records with no sablefish catch reported	34118

Table F.2 Variables included in the sablefish trap fishery standardized CPUE model, by order of importance (proportion of deviance explained) for the regional CPUE model.

Order	**Variable**	**Cumulative proportion of deviance explained (r^2)**	**Number of parameters**
1	*year*region*	0.1623	27
2	*fishing master*	0.2207	45
3	*day of year*	0.2489	48
4	*minor area*	0.2588	56
5	*day of year:minor area*	0.2796	75

Table F.3 Variables included in the sablefish trap fishery standardized CPUE model, by order of importance (proportion of deviance explained) for the coast wide CPUE model.

Order	**Variable**	**Cumulative proportion of deviance explained (r^2)**	**Number of parameters**
1	*year*region*	0.1411	14
2	*fishing master*	0.2009	32
3	*day of year*	0.2309	35
4	*minor area*	0.2462	44
5	*day of year:minor area*	0.2583	62

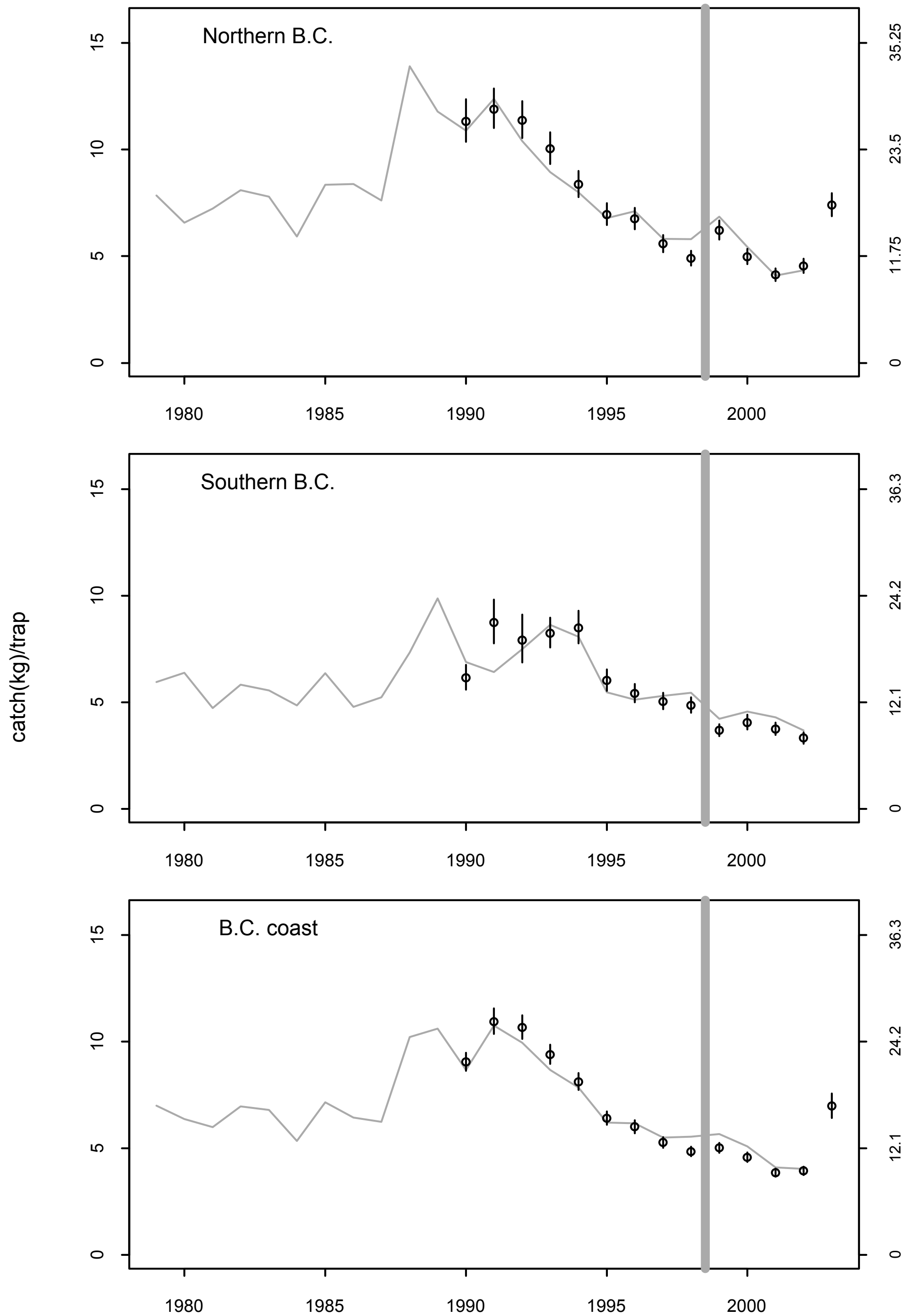


Figure F.1 Estimated *year* effects for the regional (upper two panels) and coastwide CPUE standardization model (open symbols) with ± 2 standard errors shown by vertical bars. For comparison, the nominal CPUE series are shown (gray lines).

APPENDIX G TAGGING DATA

G.1 TAG RELEASES G-1
Tag releases from sablefish survey standardized sets, 1991 to 2001 ..... *G-1*
Tag releases from sablefish survey dedicated tagging sets, 1991 to 2001 ..... *G-2*
Sablefish survey tag releases, 2002 to 2003 ..... *G-3*
Tag type *G-4*
G.2 TAG RECOVERIES G-5
G.3 DATA SELECTION G-5
Selection of tag releases and recoveries *G-5*
Data storage *G-6*
Prorating of tags with partial recovery information *G-6*
G.4 EXPLORATORY DATA ANALYSIS OF TAG RECOVERIES G-7
G.5 LITERATURE CITED G-8

G.1 Tag Releases

A brief summary of the sablefish tagging program is provided in this section. The discussion is focused on tag releases from the sablefish survey beginning in 1991 since these data are used in the stock assessment. Additional details on the tagging program can be found in Beamish et al. (1978, 1979, 1980), Beamish and McFarlane (1983), Murie et al. (1995), Smith et al. (1996), Downes et al. (1997), Wyeth and Kronlund (2003), and Wyeth et al. (2003).

The sablefish tagging program began in 1977 for the purpose of stock identification. The tagging program continued into the mid 1980s with tagging effort directed at different components of the population as program objectives changed. Beginning in 1991, tagging was integrated into the fall sablefish survey. Initially sablefish captured during the standardized survey sets were tagged and released. In 1994 "tagging sets" directed at capturing sablefish for tag and release became part of the fall survey and in 1995, offshore localities were added for the express purpose of conducting tagging sets. Sablefish have been tagged and released from standardized sets conducted in north and central coast mainland inlets. In 1996 and 1997, spring tagging trips were also conducted. In addition to the tagging conducted during the annual sablefish survey, 899 fish captured during a 1996 trawl research trip were also tagged and released. Tag releases by general geographic region and year are listed in Table G.1. Total releases at offshore locations have ranged from 1,101 tagged fish released in 1987 to 24,381 released in 1996.

Tag releases from sablefish survey standardized sets, 1991 to 2001

In 1988, an annual fall sablefish survey was initiated. Fishing was conducted at eight selected offshore localities ("indexing localities"). In 1990 the survey fishing protocols were standardized and since then the annual catch rate data have been used as an index of sablefish abundance. Beginning in 1991, tagging was introduced to the fall sablefish survey. In 1992 and 1994, additional offshore indexing localities were added (Table G.2, Figure G.1). Beginning in 1999, additional deeper sets were added at both the indexing localities and at new localities (e.g., Tasu Sound-Marble Island) but very few fish were tagged and released from these sets (Table G.2). Beginning in 1995, standardized survey sets were conducted at localities in the north and central coast mainland inlets ("inlet localities", Table G.4).

Each year, one standardized survey set was made in each of five depth strata at each locality. The depth strata were 150-250 fm (272-457 m), 250-350 fm (457-641 m), 350-450 fm (641-824 m), 450-550 fm (824-1006 m), and 550-650 fm (1006-1188 m). The fishing master of the survey vessel had discretion over the exact location of the standardized set within each survey locality. Standardized sets consisted of 25 traps baited with approximately 1 kg (2 lbs) of frozen squid in a bait bag.

At the outset of the 1991 survey, replicate sets were made at some localities and sablefish from the second set at each locality were tagged and released. As the 1991 survey progressed, the protocol shifted to tagging sablefish in excess of the biological sampling requirements of the set. For example, if fish from every third trap were sampled, fish from the first and second traps were tagged. This protocol remained in effect for the standardized sets through 2001 ("traditional standardized survey set tagging protocol"). Table G.3 shows the proportion of tags released from standardized survey sets in each offshore locality for each year. Percentages less than 100 indicate years and localities where tags were released by both standardized survey sets and dedicated tagging sets. Table G.5 shows the proportion of tags released from standardized survey sets in each inlet locality for each year.

Tag releases from sablefish survey dedicated tagging sets, 1991 to 2001

In 1994 "tagging sets" directed at capturing sablefish for tag and release were conducted in Finlayson and Mathieson Channels. In 1995, seven offshore "tagging" localities were added for the express purpose of conducting tagging sets (Table G.2, Figure G.1). The localities off the West Coast of Vancouver Island (Pisces Canyon, Estevan Point, and Father Charles Canyon) and in Queen Charlotte Sound (Middle Ground) were visited from 1995 through 2003. However, the tagging localities off the West Coast of the Queen Charlotte Islands visited in 1995 were not visited again. Rather, new localities were chosen (Rennell Sound and Tasu Sound) which, when combined with the existing indexing localities, provided better coverage of the coast. Additional localities were visited in 1997 and 1998 (Hogback and Kyuoquot Sound to Ouokinish Inlet). Beginning in 1999 a single tagging set was also conducted at each offshore indexing locality (Table G.3).

Tagging sets were targeted between 250 and 450 fm (457-824 m). Following the protocol of standardized survey sets, the fishing master of the survey vessel had discretion over the exact position of the tagging set within each locality. Tagging sets consisted of strings of 50 to 75 traps baited with approximately 1 kg of frozen squid in a bait bag and, in later years, 3 to 5 kg (6-10 lbs) of loose frozen Pacific hake (*Merluccius productus*) was also added to the traps.

For tagging sets, most of the sablefish were tagged and released with the exception of fish from an *ad hoc* selection of traps that were used for biological samples. Each year, survey guidelines specified how many sablefish should be tagged and released at each locality. Sometimes, instead of continuing tagging when the required number of tag releases was attained in a locality, the "extra" catch was retained and processed by the survey vessel to be landed as commercial catch.

In 1996 and 1997 spring tagging surveys were conducted in addition to the fall survey. Both offshore indexing and tagging localities were visited but only tagging sets were completed.

Sablefish survey tag releases, 2002 to 2003

In 2002 and 2003, the fall stock assessment survey was split into the standardized survey and the tagging program and was conducted by two charter vessels. The "standardized survey" vessel completed standardized sets at offshore indexing localities and sablefish were not tagged and released. However, sablefish captured during standardized sets at the inlet localities were tagged and released following the traditional standardized survey tagging protocol. The second "tagging" vessel conducted the offshore tagging. Three types of tagging sets were completed. All types of tagging sets were baited in the same manner with a combination of approximately 1 kg of frozen squid in a bait bag and approximately 3.5 kg of frozen hake loose in each trap. The types of tagging sets differed as follows:

1. Type 1 (**traditional**) tagging sets consisted of 65 traps and were conducted at the tagging localities and targeted at 250-450 fm (457-824 m). The goal was to tag 1000 sablefish from Type 1 sets in each locality and to maintain the historical protocol so that existing tagging analyses could be continued;
2. Type 2 (**systematic**) tagging sets consisted of 25 traps and were conducted at the offshore indexing localities. The objective of these sets was to release tagged sablefish across the depth distribution of the species in offshore waters. One set was made in each of the seven standardized survey depth strata. All sablefish captured in the Type 2 sets were tagged and released. Type 2 sets were not conducted in 2003;
3. Type 3 (**random**) tagging sets used the same gear as the Type 2 sets, but were conducted at randomly positioned fishing sites.

Type 3 random tagging sets in 2002 were conducted by randomly selecting five latitude and longitude coordinates within each of the Barkley Canyon and Hippa Island localities. The skipper was directed to make the set pass through the supplied coordinates and to stay within ± 50 fm of the depth at the supplied coordinates. All sablefish captured in the randomly selected sets were tagged and released.

In 2003 the Type 3 random tagging program was extended to a pilot study consisting of 75 sets allocated according to a stratified random design. The objective of the design was to randomly tag and release fish across depth and spatial strata inhabited by sablefish on the "offshore" B.C. coast. The design had the following characteristics:

1. Each set consisted of 25 traps baited with approximately 1 kg of frozen squid in a bait bag and 4.5 kg (10 lbs) of frozen offshore Pacific hake loose in the trap;
2. The offshore area was partitioned into 5 spatial strata with 3 depth strata within each spatial stratum for a total of 15 strata (Table G.6, Figure G.2);
3. For 2003, a total of 5 replicate sets were assigned to each stratum;
4. The sampling unit selected at random within each stratum was a 2 km by 2 km square;
5. The tagging set was required to be contained within the requisite depth stratum and pass through the selected square;
6. Sablefish caught in 50 percent of the traps were tagged; the remainder was sampled for biological characteristics.

Tag type

All sablefish were tagged using a Floy FD-68B T-bar anchor tag until 2000. Beginning in 2001, a Floy FD-94 tag was used that has similar characteristics to the FD-68B model, with an improved coating to prevent wear of the tag label. The tag is inserted approximately 1 cm below the anterior insertion of the first dorsal fin and angled back to be streamlined. Two tag labeling schemes were released in the course of tagging. The tags differ in the information printed on the tags:

B-type	REWARD PACIFIC BIO. STATION NANAIMO, B.C. CANADA B99 #####
CSA-type	REWARD CANADIAN SABLEFISH ASSOC. NANAIMO, B.C. CANADA CSA #####

The CSA-type tag was introduced in 2000 and releases continued through 2001. Due to concerns over differential return rates between tag types (it was not clear where to return the CSA-type tag), releases of the two different tag types was discontinued in 2002 with the introduction of a single tag type with the following information:

PBS/CSA-type	CSA REWARD PACIFIC BIO. STATION NANAIMO, B.C. CANADA A00 ### ###

Analyses of recoveries of tagged fish to date indicated no significant difference in return rates between the two tag types (Haist et al. 2001, Kronlund et al. 2003).

G.2 Tag Recoveries

Tagged sablefish are recovered through voluntary returns from the B.C. commercial groundfish fisheries (trawl, trap, and longline) as well as from commercial fishing in Alaska and the continental United States. Some tags are also returned from other commercial and sport fisheries. A reward system is offered through the Canadian Sablefish Association as incentive to return tags.

Table G.7 through Table G.12 summarize the annual number of tags recovered by all gear types by release year. The sablefish trap fishery accounts for the majority of tag returns (Table G.8). Some tags are returned without specific capture information (Table G.11), while for a few tag returns the capture gear is known but the year of recovery is unknown (Table G.12).

G.3 Data Selection

Selection of tag releases and recoveries

Selection criteria applied to the tagging data depend on the specific analysis. Data used in this paper were based on tag release and recovery data current to the end of July, 2003. Fish tagged and released were included in the analyses if the following criteria were met:

1. The tag release took place from 1991 to 2002 (consistency of tagging program);
2. The released fish was greater than 450 mm fork length or unknown length (adult fish);
3. Tag application took place in offshore waters (Table G.13) (offshore vulnerable population);
4. Tag application occurred from August through December (tags released at consistent time as part of the annual fall survey);
5. For tags released in 2002, the set followed a "traditional" fishing protocol (Type 1 sets and Type 2 sets targeted between 250 and 450 fm (depth strata 3 and 4, 457-824 m).

These criteria define the traditional adult offshore release data, and Table G.14 summarizes the proportion of releases that are included in the analyses.

Recovered tagged sablefish were included in the analyses provided the following criteria were met:

1. The tagged fish was recovered by a commercial sablefish trap vessel (vulnerable adult population);
2. The tagged fish was not recovered as part of research fishing (sablefish survey sets in particular have a higher probability of tag recapture than the commercial fishery);

3. The tagged fish was not recovered at a seamount (offshore vulnerable population).

These criteria define the traditional adult offshore recovery data. In addition, some tagging models have required that the tag recoveries be restricted to those occurring in the first year after release (Haist and Hilborn 2000, Haist et al. 2001, Kronlund et al. 2002, Kronlund et al. 2003).

Data storage

Sablefish tag release and recovery data are stored in a number of databases maintained by Fisheries and Oceans, Canada at the Pacific Biological Station in Nanaimo, B.C. Tag release data from 1991 to the present are stored in the Groundfish Biological (GFBio) database (http://pacpbsgfiis/sql/). Releases prior to 1990 are stored in the Microsoft Access database *Tag_Recoveries.mdb* but these data are in the process of being migrated to the GFBio database. Tag recoveries are stored in the PacSableTag database running on a SQL Server platform.

Prorating of tags with partial recovery information

The majority of tags are recovered with complete information on year of recovery, month of recovery, gear type, and area (north/south). However, the balance of tag recoveries may be missing this information in various combinations, including the most extreme case of no information, or cases such as that in Table G.12 where the gear type is known but the year of recovery is unknown. An algorithm was developed to prorate recovered tags with partial information using tags with complete information.

1. *Recovery year unknown*. Recovered tags where the year of recovery was unknown were ignored;
2. *One unknown*. Recovered tags where one of recovery month, gear, or area was unknown were assigned using the marginal probability determined from tags with complete information within each recovery year. For example, when month was unknown, the probability of month M was determined by computing the proportion of tags recovered in each month for tags with complete information, P(M);
3. *Two unknowns*. Recovered tags where two of recovery month, gear, or area were unknown were assigned using the conditional probabilities of the unknown categories given the known information within each recovery year. For example, consider the case where recovery month and gear were unknown, but area was known. There are two conditional probabilities, namely the probability of recovery month M given area A, P(M|A), and the probability of gear type G given area A, P(G|A). Assuming these events are independent, the joint probability $P(M \cap G|A)=P(M|A)P(G|A)$ was used to assign tag recoveries by unknown recovery month and area. The joint probabilities were determined by computing the appropriate proportions from tags with complete information;

4. *Three unknowns*. Recovered tags where recovery month, gear, and area were missing were assigned to the various categories by assuming independence, so that $P(M \cap G \cap A)=P(M)P(G)P(A)$. The marginal probabilities computed from tags with complete recovery information within each recovery year were used to prorate tags with three unknowns.

This algorithm is pragmatic, but occasionally resulted in situations where tags with unknown information were assigned to categories where there should be structural zeros. For example, the estimated tag recoveries after prorating occasionally assigned tags to months were there was no trap fishing and the number of tag recoveries from trap gear should be zero. This situation typically involved an estimated number of tags less than one arising from cases where one (1) tag recovery with unknown information was allocated over a number of recovery month, gear, and area categories. Previous tagging model analyses for sablefish have generally treated the "observed" tag recoveries to be the sum of tags with complete information and the estimated tag recoveries that result from prorating.

G.4 Exploratory Data Analysis of Tag Recoveries

Tagging analyses utilize the assumption that the proportion of tags in the recovered samples is related to the proportion of tags in the population of interest. Thus, examination of the tags recovered per metric tonne of fish caught is a useful first step in exploratory analyses. Exploratory plots presented here are based on actual tag recoveries, rather than prorated tag recoveries.

Figure G.3 shows the tags recovered per tonne landed for sablefish trap vessels over time for the north and south stock areas. Each circle indicates the monthly mean of tags per tonne landed, jittered along the x-axis to expose the individual points. The solid lines in each of the panels join the annual mean tags per tonne for individual vessels. The general pattern over time is one of initial increase to a peak in 1998, followed by a period without trend to 2002. The variance of the monthly values appears to have decreased since the peak in 1998, an observation that was attributed to smaller differences in reporting rates among vessels (Kronlund et al. 2003). Comparison of the trends in tags per tonne landed by vessel with the annual tag releases (lower left panel, Figure G.3) suggests that the increase over time in tags per tonne landed can be largely attributed to the increase in tags in the population. There appears to be no relationship between trap landings (lower right panel, Figure G.3) and tags per metric tonne landed.

The decline of tags over time was examined by plotting the (log) tags per tonne landed by recovery year for each release year in the north and south stock areas (Figure G.4, Figure G.5). A small number was added to the observed tag recoveries to accommodate combinations of release year, recovery year, and month where no tags were recovered by catch was recorded. The plots for release years 1991 and 1992 in both stock areas are somewhat noisy which is expected given the relatively low number of releases. The following observations can be drawn from inspection of the figures:

1. The decline in tags per tonne landed appears greater in the first three to five years after release than in subsequent years, at least for those release years with sufficient data (eg. 1994 to 1997);
2. For the north stock area, there is a consistent seasonal pattern of decrease in tags per tonne landed in December through March, with the low point typically occurring in January;
3. The seasonal pattern evident in the north stock area can be seen for some release and recovery years in the south stock area, but is not as consistent as the northern pattern. Indeed, in many recovery years the highest tags per tonne observations are highest during the first few months of the year.

For the north stock area, the seasonal patterns are consistent with the hypothesis that an influx of untagged fish enters the B.C. population in the December to March period, causing a reduction in tags per tonne returned through dilution of the tagged population. Apparently these fish subsequently become unavailable to the fishery after about March through fishery removals or movement to areas of reduced vulnerability.

G.5 Literature Cited

Beamish, R.J., C. Wood, and C. Houle. 1978. A summary of sablefish tagging studies conducted during 1977 by the Pacific Biological Station. Fish. Mar. Serv. Data Rep. 77: 102 p.

Beamish, R.J., C. Houle, C. Wood, and R. Scarsbrook. 1979. A summary of sablefish tagging and exploratory trapping studies conducted during 1978 by the Pacific Biological Station. Can. Data Rep. Fish. Aquat. Sci. 162: 113 p.

Beamish, R.J., C. Houle, and R. Scarsbrook. 1980. A summary of sablefish tagging and biological studies conducted during 1979 by the Pacific Biological Station. Can. Manuscr. Rep. Fish. Aquat. Sci. 1588: 194 p.

Beamish, R.J., G.A. McFarlane, R. Scarsbrook, D. Chilton, I. Barber, K. Best, A. Cass, and W. Shaw. 1983. A summary of sablefish tagging and biological studies conducted during 1980 and 1981 by the Pacific Biological Station. Can. Manuscr. Rep. Fish. Aquat. Sci. 1732: 135 p.

Beamish, R.J. and G.A. McFarlane. 1983. Summary of results of the Canadian sablefish tagging program. p. 147-183. *In* Proceedings of the Second Lowell Wakefield Fisheries Symposium. Anchorage, AK. Alaska Sea Grant Report 83-8.

Downes, A.J., Andrews, W.T., Smith, M.S., Saunders, M.W., and G.D. Jewsbury. 1997. Cruise details of sablefish (*Anoplopoma fimbria*) surveys conducted in B.C. waters, 1994-1995. Can. Data. Rep. Fish. Aquat. Sci. 1007: 106 p.

Haist, V. and R. Hilborn. 2000. Sablefish stock assessment for 2000 and recommended yield options for 2001. Can. Stock. Assess. Sec. Res. Doc. 2000/157. 78 p.

Haist, V., Hilborn, R., and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. Can. Sci. Advisory Res. Doc. 2001/135. 54 p.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

Kronlund, A.R., M. Wyeth, and R. Hilborn. 2002. Review of survey, commercial fishery, and tagging data for sablefish (*Anoplopoma fimbria*) in British Columbia: Supplement to the November 2001 sablefish stock assessment. Can. Sci. Adv. Sec. Res. Doc. 2002/074. 109 p.

Murie, D.J., Mitton, W., Saunders, M.W., and G.A. McFarlane. 1995. A summary of sablefish tagging and biological studies conducted during 1982-1987 by the Pacific Biological Station. Can. Data Rep. Fish. Aquat. Sci. 959: 84 p.

Smith, M.S., Saunders, M.W. and W.T. Andrews. 1996. Cruise details of sablefish (*Anoplopoma fimbria*) surveys conducted in B.C. waters 1988-1993. Can. Data Rep. Fish. Aquat. Sci. 976: 129 p.

Wyeth, M.R. and A.R. Kronlund. 2003. Sablefish (*Anoplopoma fimbria*) research and assessment surveys conducted in British Columbia waters from 1996 to 2000. Can. Data Rep. Fish. Aquat. Sci. 1116: 130 p.

Wyeth, M.R., A.R. Kronlund, and M. Elfert. 2003. Summary of the 2001 British Columbia sablefish (*Anoplopoma fimbria*) research and assessment survey. Can. Data Rep. Fish. Aquat. Sci. 1118. 54 p.

Table G.1 Number of tagged sablefish released by year and area.

Year	Offshore North	Offshore South	Offshore Total	Hecate Strait	Mainland Inlets	Seamount	Dixon Entrance	Queen Charlotte Sound	Strait of Georgia	Total
1977	5,159	5,505	**10,664**							**10,664**
1978	5,960	4,342	**10,302**					594		**10,896**
1979	6,621	9,112	**15,733**	10,417				15,121	26	**41,297**
1980	4,141	5,217	**9,358**	12,039	7,020		466	1,187	18	**30,088**
1981	10,430		**10,430**	2,983				9,323		**22,736**
1982	3,008	3,436	**6,444**					596		**7,040**
1983	4,002	4,023	**8,025**							**8,025**
1984	7,698	1,359	**9,057**	654				1,019		**10,730**
1985	3,025	5,303	**8,328**							**8,328**
1987		1,101	**1,101**			616				**1,717**
1991	958	1,489	**2,447**							**2,447**
1992	1,308	2,276	**3,584**							**3,584**
1993	2,487	4,531	**7,018**							**7,018**
1994	1,622	1,982	**3,604**		3,434					**7,038**
1995	7,561	5,141	**12,702**		3,198					**15,900**
1996	10,657	13,683	**24,340**		3,894					**28,234**
1997	5,473	11,021	**16,494**		3,144					**19,638**
1998	3,010	12,946	**15,956**		6,009					**21,965**
1999	7,031	10,760	**17,791**		9,620					**27,411**
2000	6,738	13,063	**19,801**		3,114					**22,915**
2001	4,087	10,065	**14,152**		4,094					**18,246**
2002	7,032	9,276	**16,308**		3,549					**19,857**
Total	**108,008**	**135,631**	**243,639**	**26,093**	**47,076**	**616**	**466**	**27,840**	**44**	**345,774**

Table G.2 Number of tags released at each offshore locality during fall sablefish surveys from 1991 to 2002. Note that this summary does not include 899 tags released from a trawl research trip in 1996 as well as 15,139 and 9,355 tags released during spring surveys in 1996 and 1997, respectively.

Locality	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Langara Island-North Frederick	507	217	483	227	154	138		258	846	442	141	562	**3,975**
Rennell Sound						698	508		2,139	2,428	1,357	990	**8,120**
Hippa Island		258	504	279	198	325		262	380	366	270	1,307	**4,149**
Buck Point	170	483	570	346	155	230	64	194	289	678	557	1,176	**4,912**
Tasu Sound						715	487	2,013	1,664	1,731	1,124	996	**8,730**
Gowgaia Bay	281	350	930	469	1,287	139	109	236	469	561	86	849	**5,766**
Cape St. James				301	145	147		47	839	522	552	1,152	**3,705**
Middle Ground					1,688	1,578	1,082	2,048	2,108	1,953	2,126	977	**13,560**
Triangle Island	69	420	575	238	498	178	66	277	784	994	497	1,304	**5,900**
Pisces Canyon					158	1,277	1,119	2,051	2,016	1,991	1,171	972	**10,755**
Quatsino Sound	466	528	687	198	290			156	581	744	659	937	**5,246**
Esperanza Inlet		587	1,396	464	564	196	297	302	291	1,034	348	1,027	**6,506**
Estevan Point					1,360	1,238	1,476	4,321	1,712	2,271	2,608	1,125	**16,111**
Father Charles Canyon					1,296	945	1,087	1,171	2,294	2,256	1,764	843	**11,656**
Barkley Canyon	954	741	1,873	882	695	498	535	281	1,379	1,820	892	2,091	**12,641**
Frederick Island					1,953								**1,953**
Hogback							309						**309**
Chads Point					954								**954**
Tasu Sound-Marble Island										10			**10**
Anthony Island					1,027								**1,027**
Solander Island				200	280								**480**
Kyuquot Sound-Ouokinish Inlet								2,339					**2,339**
Offshore Total	**2,447**	**3,584**	**7,018**	**3,604**	**12,702**	**8,302**	**7,139**	**15,956**	**17,791**	**19,801**	**14,152**	**16,308**	**128,804**

Table G.3 Percentage of tags released from standardized survey sets at each offshore locality during fall sablefish surveys from 1991 to 2002. Percentages less than 100 indicate that the balance of the tags was released from tagging sets.

Locality	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean
Langara Island-North Frederick	100	100	100	100	100	100		100	22.3	2.5	0	0	**65.9**
Rennell Sound						0	0		0	0	0	0	**0**
Hippa Island		100	100	100	100	100		100	0	2.2	0	0	**60.2**
Buck Point	100	100	100	100	100	100	100	100	0	12.7	0	0	**67.7**
Tasu Sound						0	0	0	0	0	0	0	**0**
Gowgaia Bay	100	100	100	100	29.4	100	100	100	0	11.0	0	0	**61.7**
Cape St. James				100	100	100		100	19.4	16.7	4.7	0	**55.1**
Middle Ground					0	0	0	0	0	0	0	0	**0**
Triangle Island	100	100	100	100	100	100	100	100	5.23	18.8	0	0	**68.7**
Pisces Canyon					0	0	0	0	0	0	0	0	**0**
Quatsino Sound	100	100	100	100	100			100	37.4	37.6	28.5	0	**70.4**
Esperanza Inlet		100	100	100	100	100	100	100	41.9	33.4	12.9	0	**71.7**
Estevan Point					0	0	0	0	0	0	0	0	**0**
Father Charles Canyon					0	0	0	0	0	0	0	0	**0**
Barkley Canyon	100	100	100	100	100	100	100	100	15.4	64.9	28.4	0	**75.7**
Frederick Island					0								**0**
Hogback							0						**0**
Chads Point					0								**0**
Tasu Sound-Marble Island										100			**100**
Anthony Island					0								**0**
Solander Island				100	100								**100**
Kyuquot Sound-Ouokinish Inlet								0					**0**
Offshore Mean	**100**	**100**	**100**	**100**	**54.7**	**57.1**	**41.7**	**60.0**	**9.4**	**18.7**	**5.0**	**0**	**53.9**

Table G.4 Number of tags released in each inlet locality during fall sablefish surveys from 1994 to 2002.

Locality	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Portland Inlet	646	416	1,010	527	2,112	3,799	541	1,251	528	**10,830**
Gil Island	1,439	679	1,540	1,240	2,296	3,606	1,792	1,301	1,500	**15,393**
Finlayson Channel	693	672	345	662	1,029	1,356	327	910	976	**6,970**
Mathieson Channel	656		81							**737**
Dean/Burke Channel		1,431	918	715	572	859	454	632	545	**6,126**
Inlet Total	**3,434**	**3,198**	**3,894**	**3,144**	**6,009**	**9,620**	**3,114**	**4,094**	**3,549**	**40,056**

Table G.5 Proportion of tags released from standardized survey sets in each inlet locality during fall sablefish surveys from 1994 to 2002. The remainder of the tags was released from tagging sets.

Locality	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean
Portland Inlet	100	100	100	100	100	100	100	100	100	**100**
Gil Island	100	100	100	100	100	100	100	100	100	**100**
Finlayson Channel	0	100	100	100	100	100	100	100	100	**88.9**
Dean/Burke Channel		100	100	100	100	100	100	100	100	**100**
Mathieson Channel	0		100							**50**
Inlet Mean	**50**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**94.4**

Table G.6 Summary of stratified random survey design used for 75 tagging sets in 2003. The area (km^2) of each spatial (**S**) and depth (**RD**) stratum is indicated, with the number of possible 2 km by 2km sampling units indicated in brackets ().

Stratum	**RD1** 100-250 fm (183-456.9 m)	**RD2** 250-450 fm (457-822.9 m)	**RD3** 450-750 fm (823-1371.9 m)	All Depths
S1	1,088 (272)	1,236 (309)	2,024 (506)	**4,348 (1,087)**
S2	976 (244)	1,252 (313)	2,236 (559)	**4,464 (1,116)**
S3	3,628 (907)	1,240 (310)	1,372 (343)	**6,240 (1,560)**
S4	456 (114)	496 (124)	1,384 (346)	**2,336 (584)**
S5	1,508 (377)	1,020 (255)	1,672 (418)	**4,200 (1,050)**
All Areas	**7,656 (1,914)**	**5,244 (1,311)**	**8,688 (2,172)**	**21,588 (5,397)**

Table G.7 Number of tagged sablefish recovered by all gear types in each year by year of tag release (Includes all releases and all recoveries.).

	Recovery Year																										
Release Year	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Total**
1977	138	631	267	200	131	73	47	41	27	19	8	12	6	4	9	7	8	1	1	2	10	5	4	2	8	6		**1667**
1978		221	319	286	128	51	43	30	9	8	5	9	11	5	3	4	2	1		1	2	3	4	2	1	2		**1150**
1979			831	1384	617	409	206	169	169	224	65	89	55	34	20	33	27	7	3	21	23	40	20	6	21	9		**4482**
1980				1078	980	646	388	313	103	113	50	60	71	44	28	23	32	6	1	25	20	16	10	15	24	3		**4049**
1981					273	583	343	188	99	97	47	53	53	48	32	34	27	4		26	13	16	14	13	9	2	1	**1975**
1982							665	356	91	60	18	32	39	24	13	23	15	1		7	11	8	8	5	7	1		**1384**
1983								106	39	55	26	19	18	11	3	3	6	1		3	6	1	3	6	4			**310**
1984								252	166	165	57	39	24	24	25	22	10	2		14	13	17	13	9	7	11		**870**
1985									114	348	72	62	43	35	15	31	19	2	1	7	16	25	9	6	9	2	1	**817**
1987											6	25	21	8	5	2				1	1	2		2	1			**74**
1991															16	100	48	39	29	17	17	15	8	9	11	5	1	**315**
1992																13	121	97	64	42	29	44	32	9	20	15	3	**489**
1993																	6	421	218	70	91	95	72	45	42	28	1	**1089**
1994																		13	416	206	227	216	127	76	61	46	5	**1393**
1995																			85	1269	913	591	374	245	463	89	22	**4051**
1996																				438	2134	1337	671	452	372	235	29	**5668**
1997																					1213	2259	907	492	367	236	37	**5511**
1998																						321	1742	1108	749	479	49	**4448**
1999																							234	2278	1430	922	111	**4975**
2000																								149	2043	917	102	**3211**
2001																									134	1534	136	**1804**
2002																										95	293	**388**
Total	**138**	**852**	**1417**	**2948**	**2129**	**1762**	**1692**	**1455**	**817**	**1089**	**354**	**400**	**341**	**237**	**169**	**295**	**321**	**595**	**818**	**2149**	**4739**	**5011**	**4252**	**4929**	**5783**	**4542**	**498**	**49732**

Table G.8 Number of tagged sablefish recovered by trap gear in each year by year of tag release (Includes all releases and all recoveries.).

	Recovery Year																											
Release Year	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Total**
1977	122	578	188	163	115	66	35	36	17	15	4	9	2		2	3	2			1	5	3		1	3	3		**1373**
1978		200	246	257	113	47	30	26	7	5	1	3	7	4		2	1				2	1	1			1		**954**
1979			617	1146	517	338	132	118	122	180	13	48	17	8	7	10	8	2		9	13	21	9	2	10	6		**3353**
1980				992	832	527	283	264	66	56	14	17	20	13	12	6	11	3		7	13	6	5	4	7			**3158**
1981					207	453	231	140	55	45	7	14	8	8	6	11	6	2		12	5	5	6	5	3			**1229**
1982							521	321	60	34	5	13	13	8	2	5	3	1		4	6	4	3	4	4			**1011**
1983								72	24	36	4	8	2	1		1				1	3	1	1	1	3			**158**
1984								229	122	114	20	19	5	6	9	7	3	1		9	8	12	11	8	2	5		**590**
1985									75	292	29	44	15	18	5	10	7		1	5	12	23	4	4	3			**547**
1987											3	14	5	2	2	1						1		1				**29**
1991															13	71	30	18	19	9	13	13	7	2	1	4		**200**
1992																10	75	58	41	27	23	25	20	5	12	8		**304**
1993																	2	261	139	45	56	70	44	13	27	13		**670**
1994																		11	317	163	183	184	93	46	43	29	1	**1070**
1995																			80	1071	739	503	270	141	86	45	4	**2939**
1996																				334	1845	1103	452	260	216	116	6	**4332**
1997																					1125	1984	666	300	243	128	9	**4455**
1998																						296	1381	729	491	284	10	**3191**
1999																							148	1571	931	560	32	**3242**
2000																								100	1587	614	35	**2336**
2001																									116	1150	50	**1316**
2002																										73	165	**238**
Total	**122**	**778**	**1051**	**2558**	**1784**	**1431**	**1232**	**1206**	**548**	**777**	**100**	**189**	**94**	**68**	**58**	**137**	**148**	**357**	**597**	**1697**	**4051**	**4255**	**3121**	**3197**	**3788**	**2966**	**147**	**36457**

Table G.9 Number of tagged sablefish recovered by longline gear in each year by year of tag release (Includes all releases and all recoveries.).

Release Year	Recovery Year: 1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
1977	14	33	52	25	15	6	10	4	5	2	4	2		1	2	2	4		1	1	4		2		4	1		**194**
1978		21	64	26	15	4	11	3		3	4	4		1	1	1	1						2	2	1	1		**165**
1979			174	89	71	56	57	34	28	26	32	21	15	15	5	14	11		2	8	4	10	7	1	4	1		**685**
1980				57	106	93	94	37	27	40	28	27	23	20	10	9	14	1	1	14	4	8	3	9	11	1		**637**
1981					26	105	93	34	26	29	28	18	23	22	16	12	9			8	7	9	6	8	3	2	1	**485**
1982							125	22	21	18	10	13	6	8	7	11	6			2	5	3	3	1	2			**263**
1983								6	6	10	16	8	8	5	3	2	3			2	2		1	2	1			**75**
1984								10	24	35	25	11	6	12	12	9	2			5	2	4	3		3	4		**167**
1985									7	32	17	9	11	11	3	13	7			2	3	1	3	2	3	1		**125**
1987												4	4	2	1					1	1	1		1				**15**
1991															1	13	15	8	6	6	3	1	1	6	6	1	1	**68**
1992																2	23	19	15	10	6	14	4	4	7	5	1	**110**
1993																	1	63	53	17	32	18	21	21	13	9		**248**
1994																			73	31	38	27	22	27	14	13	2	**247**
1995																			3	151	135	72	81	79	55	25	11	**612**
1996																				82	221	174	162	139	105	82	7	**972**
1997																					64	208	179	153	99	75	12	**790**
1998																						9	226	290	202	133	23	**883**
1999																							46	572	411	247	48	**1324**
2000																								28	324	190	44	**586**
2001																									7	211	45	**263**
2002																										5	58	**63**
Total	**14**	**54**	**290**	**197**	**233**	**264**	**390**	**150**	**144**	**195**	**164**	**117**	**96**	**97**	**61**	**88**	**96**	**91**	**154**	**340**	**531**	**559**	**772**	**1345**	**1275**	**1002**	**195**	**8914**

Table G.10 Number of tagged sablefish recovered by trawl gear in each year by year of tag release (Includes all releases and all recoveries.).

Release Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
	Recovery Year																											
1977		8	4	8		1	1	1	2					2	1						1	1	2	1	1	1		**35**
1978													1										1					**2**
1979			26	135	21	14	9	11	7	7	3	3	1	3	1	1	1			3	5	9	4	3	7	2		**276**
1980				26	37	22	9	6	2	1		1	1	3	1	1					1	1		2	5	1		**120**
1981					37	23	14	7	4	2	1	3	2	1	1	2	2				1				3			**103**
1982							16	7	1	1		1	2	1	1		1						1		1			**33**
1983								19	2	2	1	1	1				1	1			1		1	3				**33**
1984								9	6	3	1	2		1	2		1				3		1	1	2	2		**34**
1985									27	4	6	4	2	1	1	2		1			2		2		3	1	1	**57**
1987											2	2	3		1	1									1			**10**
1991																3		1		2	1			1	4			**12**
1992																1	1	2	1	1		4	4		1	2	2	**19**
1993																		18	1	1	2	4	4	6	2	4	1	**43**
1994																			1	2	6	3	8	2	3	3	2	**30**
1995																				14	33	13	16	18	20	16	7	**137**
1996																				19	65	55	45	37	47	33	15	**316**
1997																					21	56	52	31	22	25	15	**222**
1998																						8	121	62	50	47	13	**301**
1999																							39	87	79	93	22	**320**
2000																								21	122	100	21	**264**
2001																									11	156	38	**205**
2002																										17	67	**84**
Total	**0**	**8**	**30**	**169**	**95**	**60**	**49**	**60**	**51**	**20**	**14**	**17**	**13**	**12**	**9**	**11**	**7**	**23**	**3**	**42**	**142**	**154**	**301**	**275**	**384**	**486**	**137**	**2572**

Table G.11 Number of tagged sablefish recovered by other or unknown gear types in each year by year of tag release (Includes all releases and all recoveries.).

Release Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
1977	2	12	23	4	1		1		3	2		1	4	1	4	2	2	1				1				1		**65**
1978			9	3			2	1	2			2	3		2	1		1		1		2						**29**
1979			14	14	8	1	8	6	12	11	17	17	22	8	7	8	7	5	1	1	1							**168**
1980				3	5	4	2	6	8	16	8	15	27	8	5	7	7	2		4	2	1	2		1	1		**134**
1981					3	2	5	7	14	21	11	18	20	17	9	9	10	2		6		2	2			1		**159**
1982							3	6	9	7	3	5	18	7	3	7	5			1		1	1			1		**77**
1983								9	7	7	5	2	7	5			2											**44**
1984								4	14	13	11	7	13	5	2	6	4	1				1	1		1			**83**
1985									5	20	20	5	15	5	6	6	5	1				1						**89**
1987											1	5	9	4	1													**20**
1991															2	13	3	12	4			1						**35**
1992																	22	18	7	4		1	4					**56**
1993																	3	79	26	7	1	3	3	5		2		**129**
1994																		2	25	10		2	4	1	1	1		**46**
1995																			2	33	6	3	7	7	2	3		**63**
1996																				3	3	5	12	16	4	4	1	**48**
1997																					3	11	10	8	3	8	1	**44**
1998																						8	14	27	6	15	3	**73**
1999																							1	48	9	22	9	**89**
2000																									10	13	2	**25**
2001																										17	3	**20**
2002																											3	**3**
Total	**2**	**12**	**46**	**24**	**17**	**7**	**21**	**39**	**74**	**97**	**76**	**77**	**138**	**60**	**41**	**59**	**70**	**124**	**65**	**70**	**16**	**43**	**61**	**112**	**37**	**89**	**19**	**1496**

Table G.12 Number of tags recovered by known gear types but in unknown years by year of tag release. The table includes all releases and all recoveries.

Release Year	Trap	Longline	Trawl	Other and Unknown Gear	All Gear Types
1977				3	**3**
1978				1	**1**
1979	1		1	13	**15**
1980	2	1		2	**5**
1981		1		1	**2**
1982	1			3	**4**
1983				1	**1**
1984	2			4	**6**
1985	1		1	5	**7**
1987					**0**
1991	1	1		1	**3**
1992	1		4	9	**14**
1993	10	3	2	3	**18**
1994	3	1	1	2	**7**
1995	36	10	12	25	**83**
1996	50	7	17	27	**101**
1997	66	7	13	22	**108**
1998	5	4	3	17	**29**
1999		2		14	**16**
2000	2			7	**9**
2001		1	1	14	**16**
2002					**0**
Total	**181**	**38**	**55**	**174**	**448**

Table G.13 Specific selection criteria that define a tag release location as offshore.

Fisheries and Oceans, Groundfish Statistical Areas		
Major	**Minor**	**Locality**
3	all	all
4	all	all
9	all	all
6	8	0, 6, 9, 10, 12, 14, 15
5	11	0, 4, 6-12,

Table G.14 Percentage of tag releases selected for tag recovery analysis by survey locality and year. Note that 92.8% of the releases from the 1996 trawl research trip are also included in the analyses whereas none of the 1996 and 1997 spring releases are included.

Locality	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Langara Island-North Frederick	100	100	100	100	100	100		100	99.9	99.8	99.3	61.0	**94.4**
Rennell Sound						100	100		100	99.7	100	100	**99.9**
Hippa Island		100	99.8	100	100	100		99.6	99.7	99.2	99.6	35.0	**79.3**
Buck Point	100	100	99.6	100	100	100	100	100	100	99.7	100	60.6	**90.5**
Tasu Sound						100	100	99.9	99.8	99.8	99.9	99.9	**99.9**
Gowgaia Bay	100	100	99.9	100	100	100	100	99.6	99.8	99.8	100	42.8	**91.5**
Cape St. James				100	100	100		100	99.6	99.8	100	47.6	**83.6**
Middle Ground					99.9	100	100	99.9	99.7	100	100	100	**99.9**
Triangle Island	100	100	100	100	100	100	100	100	100	100	100	30.3	**84.6**
Pisces Canyon					100	100	100	99.6	99.9	99.7	100	100	**99.8**
Quatsino Sound	99.4	99.8	100	100	100			100	99.8	99.9	99.8	30.5	**87.5**
Esperanza Inlet		99.8	99.9	100	99.8	100	100	99.3	100	99.7	99.7	32.3	**89.2**
Estevan Point					100	99.8	99.9	99.7	99.9	99.7	99.9	99.9	**99.8**
Father Charles Canyon					99.9	100	100	99.7	99.7	100	100	100	**99.9**
Barkley Canyon	99.5	99.9	99.9	99.9	100	99.8	100	100	100	99.9	100	24.1	**87.4**
Frederick Island					100								**100**
Hogback							100						**100**
Chads Point					99.9								**99.9**
Tasu Sound-Marble Island										100			**100**
Anthony Island					100								**100**
Solander Island				100	100								**100**
Kyuquot Sound-Ouokinish Inlet								99.7					**99.7**
Offshore Total	**99.7**	**99.9**	**99.9**	**100.0**	**100.0**	**100.0**	**100.0**	**99.7**	**99.8**	**99.8**	**99.9**	**60.3**	**94.9**

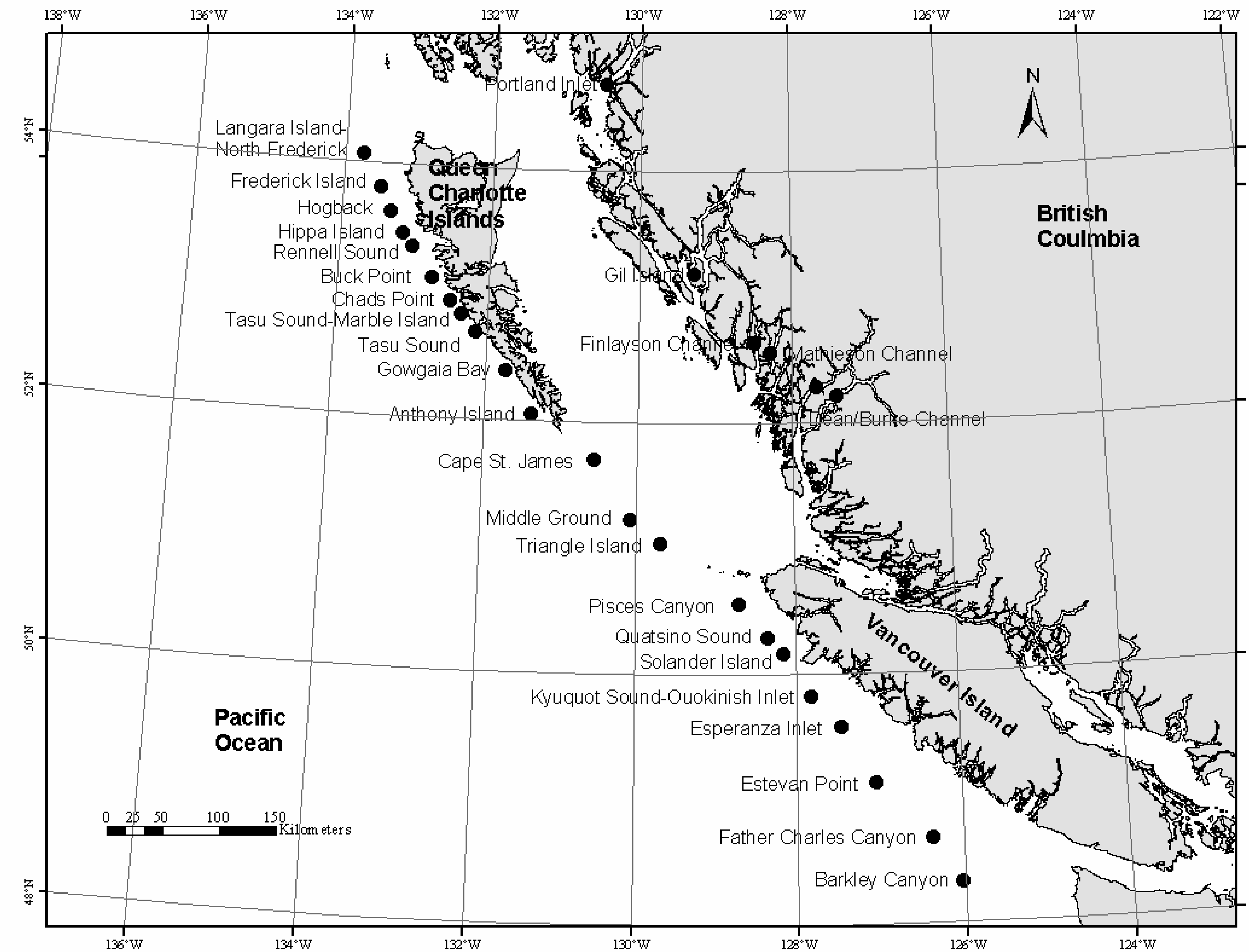


Figure G.1 Tag release localities used for the annual sablefish stock assessment survey, 1991 to 2003.

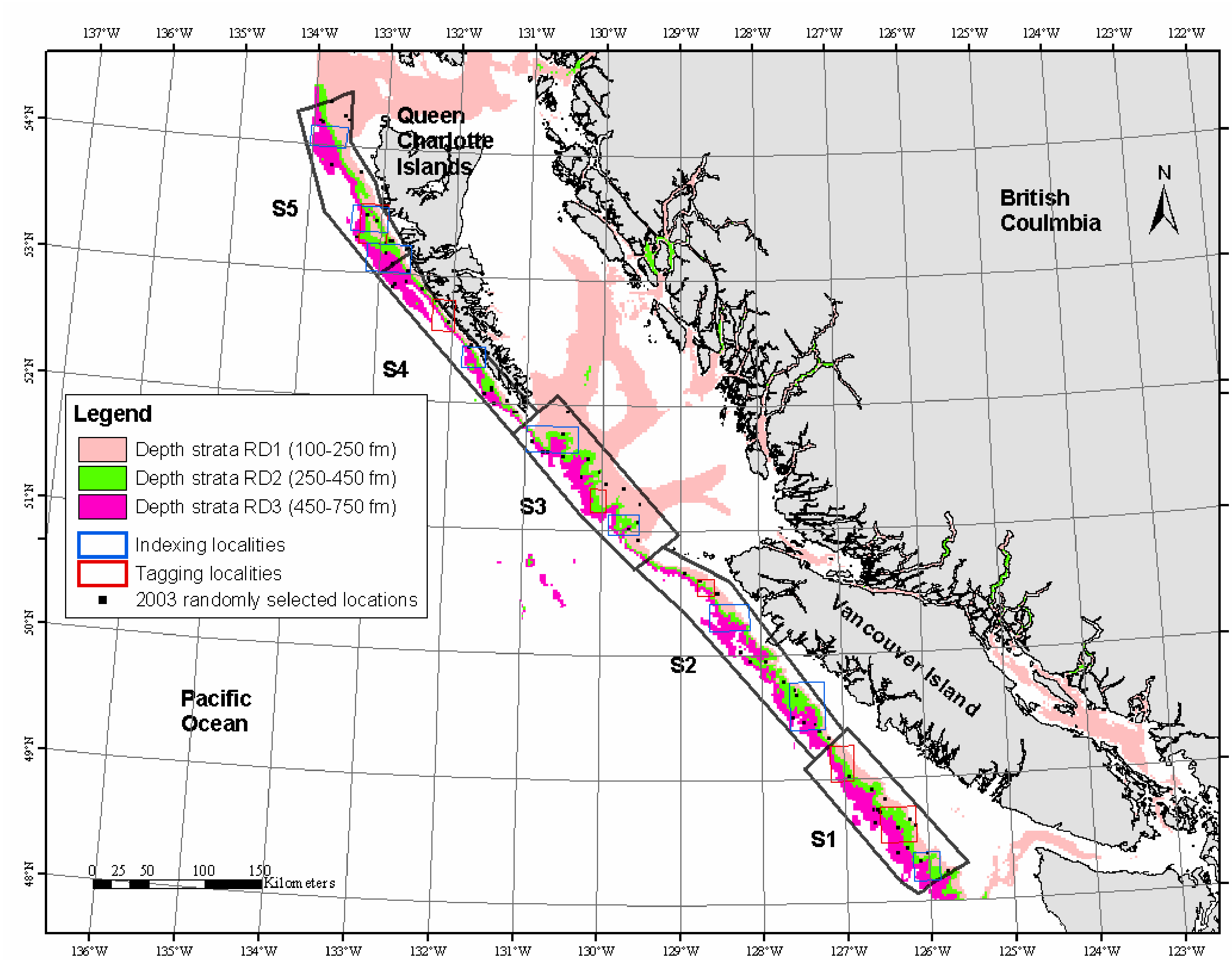


Figure G.2 Summary of the stratified random sablefish survey design showing area strata, depth strata and the randomly selected 2 km by 2 km squares visited in 2003. The traditional tagging and indexing localities are also shown.

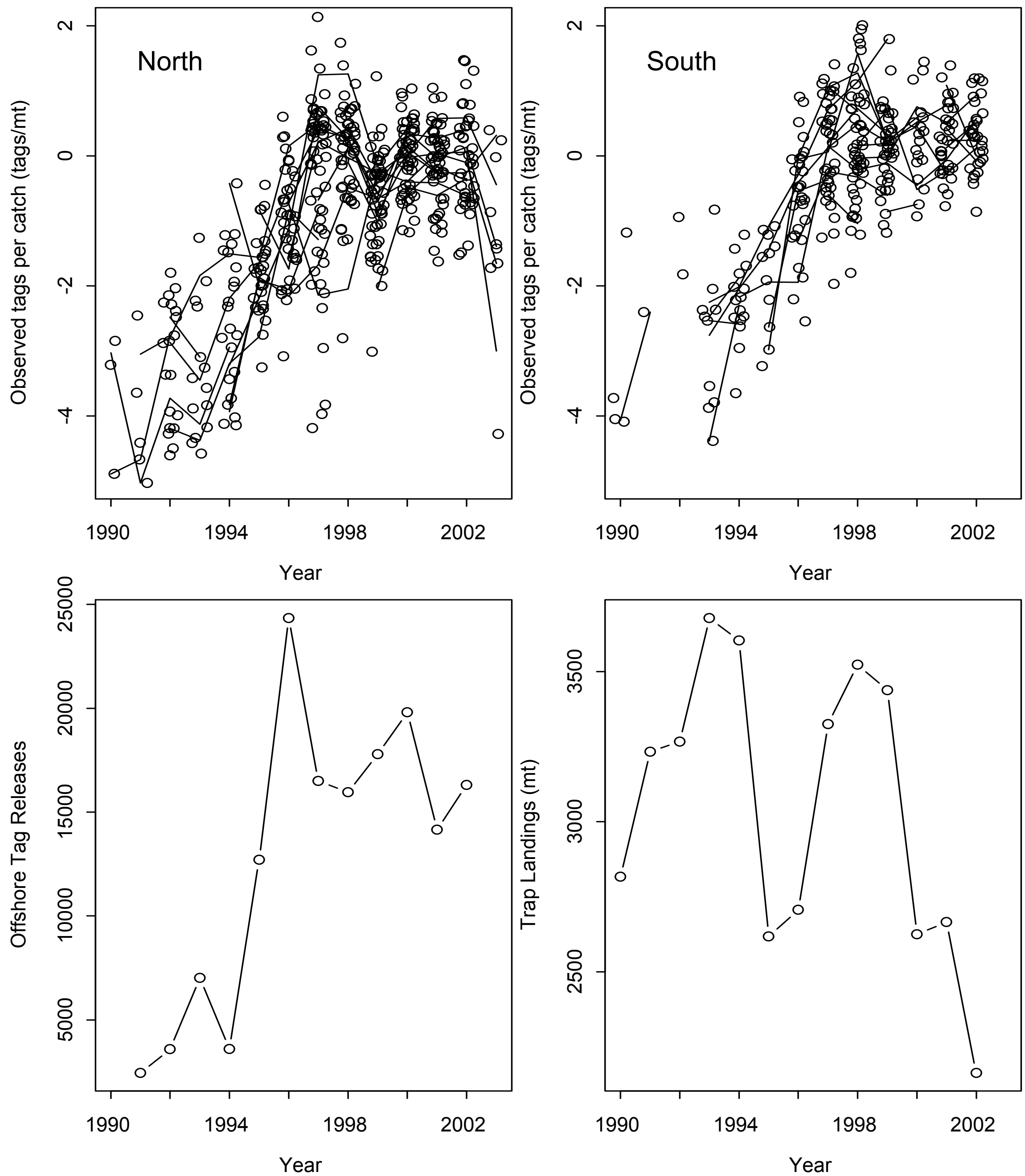


Figure G.3 Tags per metric tonne landed for trap vessels by year (upper panels). Each circle represents the monthly mean for a vessel. The solid lines join the annual mean tags per metric tonne landed for individual vessels. Lower panels show offshore tag releases (left) and trap landings (right) by year.

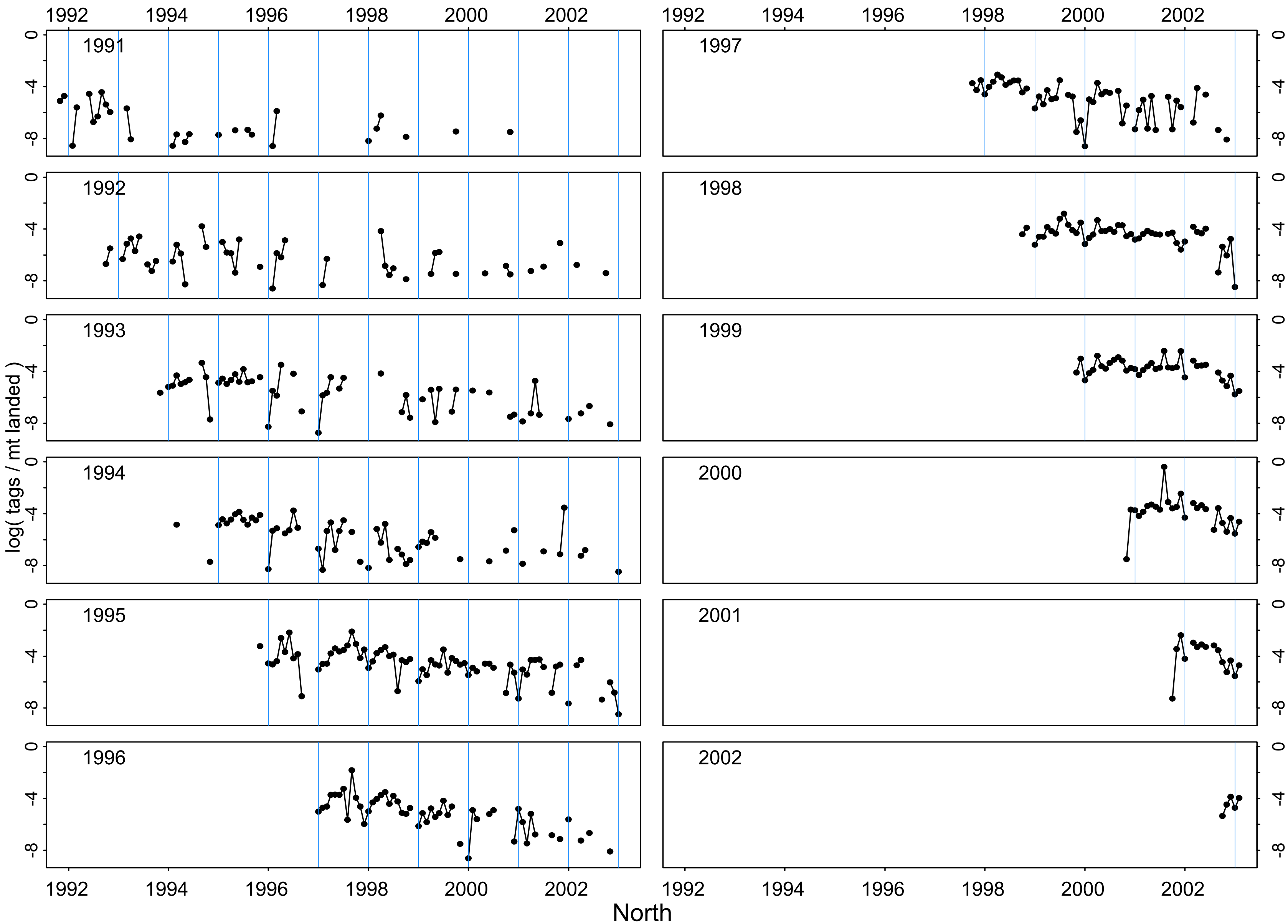


Figure G.4 Tags per tonne landed plotted against recovery year by release year (panels) for the north stock area.

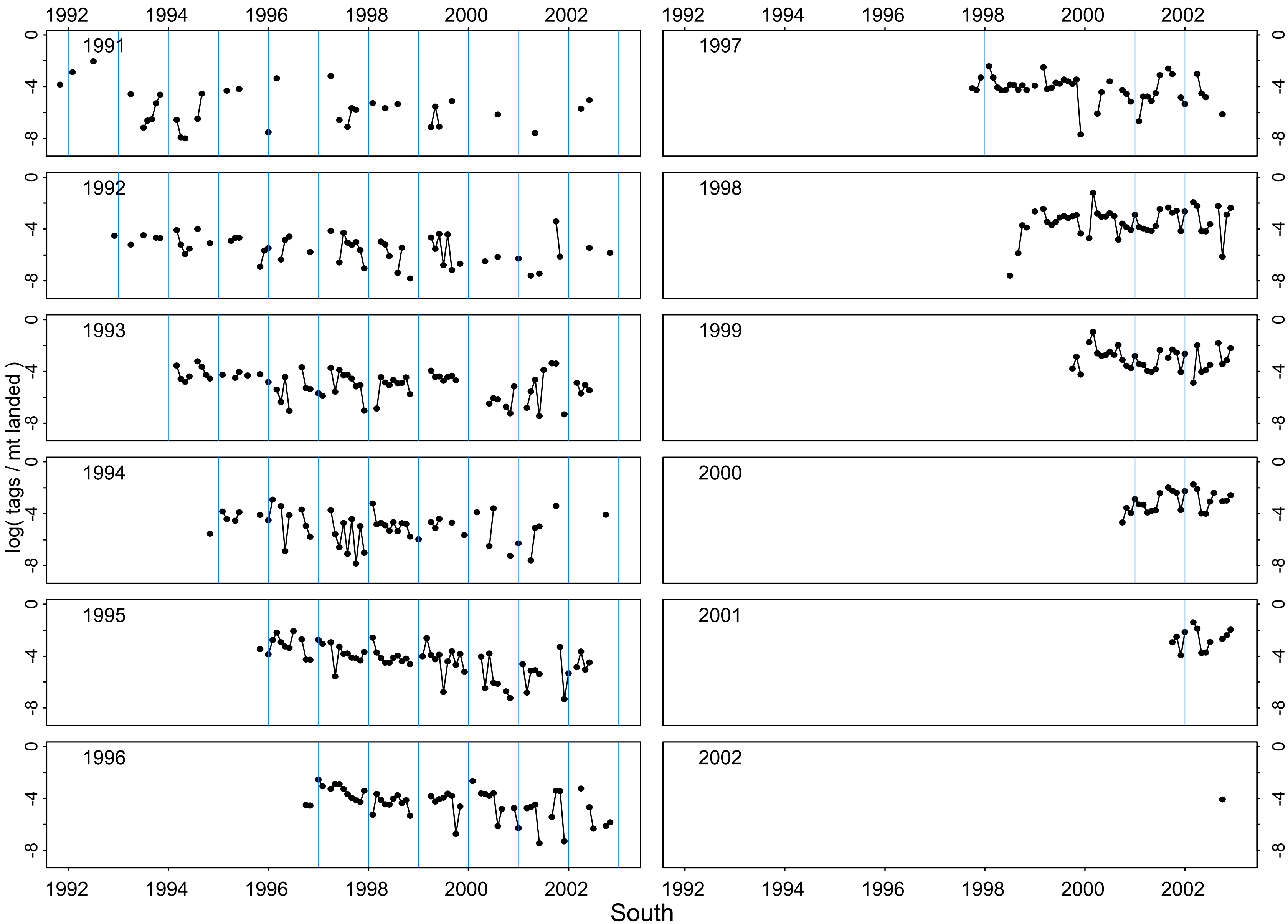


Figure G.5 Tags per metric tonne landed plotted against recovery year by release year (panels) for the south stock area.

APPENDIX H ANALYSIS OF TAG-RECOVERY DATA

H.1 BACKGROUND H-1
H.2 TAG REPORTING RATES H-3
H.3 NEW TAGGING MODEL H-4
Model description *H-4*
Details of fixed parameters *H-7*
Data selection *H-9*
Model results *H-9*
H.4 COMPARISON TO PREVIOUS TAGGING MODEL RESULTS H-11
H.5 SUMMARY H-11
H.6 LITERATURE CITED H-12

H.1 Background

Tagging was introduced to the fall sablefish surveys in 1991. The objective of the tagging was to release marked fish at each standardized survey locality and at depths where most commercial fishing effort occurred (Haist et al. 2001, Appendix G). Seven additional offshore sites for tag releases were added in 1995, but the degree to which these changes in the spatial pattern of releases have biased tagging estimates is not known. Stock assessments of British Columbia sablefish during the late 1990s relied primarily on tag-recovery information to index stock abundance (Saunders et al. 1996, Haist et al 1997, 1999b, Haist and Hilborn 2000, Haist et al. 2001, Kronlund et al. 2003). Tag releases have been large, and tag-reporting rates are thought to be high (Appendix G, Appendix B in Haist et al. 1999b).

Haist et al. (1999b) conducted an analysis of tag-recovery data that concluded tag disappearance rates in the first five years after release were high at an instantaneous rate of about Z=0.5, but declined considerably thereafter to about Z=0.2. This feature of the data is consistent with a hypothesis of fish moving to an unfished area, or becoming less vulnerable to Canadian fishing through movement or behavioural changes. The hypothesis of fish movement posed problems for the integrated catch-at-age and tag-recovery models of 1996 and 1997, which treated the B.C. population as closed, and could not quantitatively accommodate fluxes of fish from outside the defined stock area. An attempt to address movement out of the Canadian zone was developed for 1998 (Haist et al. 1999a,b), but the model tried to explain the high disappearance rate of fish in the first five years following release by assigning large amounts of biomass into southern deep-water and Alaska strata. This result was considered implausible, and further attempts to resolve tag movement were placed in hiatus pending improvement of the underlying data.

Since development of the integrated catch-age tag-recovery model was discontinued, two different tag recovery models have been applied to sablefish:

1. *Deterministic "Petersen" Tagging Model*. The deterministic model was a simple Petersen-type mark recapture model used in the 2000 through January 2002 stock assessments (Haist and Hilborn 2000, Haist et al. 2001, Kronlund et al. 2002, updated in Kronlund et al. 2003). The deterministic model used tag returns from the sablefish trap fishery that had been released in the previous year to estimate annual *trap vulnerable* biomass and exploitation rates.

2. *Monthly Tagging Model.* The monthly tagging model (Kronlund et al. 2003) was a stochastic extension of the deterministic model that incorporated stock biomass and tag dynamics. Like the deterministic model, only tag recoveries from the trap fishery in the year following release were used. The model was unique in that the biomass in December of any year was not linked to the January biomass of the following year. Also, the tagged fish were not treated the same as untagged fish in that only tagged fish could emigrate. The monthly effect was introduced to accommodate known seasonal differences in tag return rates and the effects of management measures which restricted fishing, particularly in early 2002 (Kronlund et al. 2003). The pattern of estimated month effects meant that, on average, during the January through March period there were fewer tags being captured per tonne of fish landed. The magnitude of the month effect suggested that an amount of untagged fish about equal to the trap vulnerable population becomes available to the B.C. trap fishery from about December to March and subsequently becomes unavailable to the fishery. Fishers believe that there is movement of fish from Alaska early in the year and northern catch rates are typically high during that period (Appendix G). The magnitude of this effect may have been low in the late 2000 to early 2002 period, when the trap vulnerable biomass estimates were lowest.

Problems inherent in the analysis of tag return data for B.C. sablefish include:

(1) *Failure of standard tagging model assumptions*. The tag-recovery data fail to meet the standard assumptions of standard tagging models, at least one of which must be satisfied for valid inference:

- *Random tag application*. In general, tags were applied in locations and depth zones that represent the "core" of commercial fishing effort (over 80 percent of tags were applied between 250 and 450 fm);
- *Random tag recovery*. Only recoveries from the trap fishery are utilized which has restricted spatial and depth distribution relative to the population distribution;
- *Complete mixing of tags*. Table 9 in Haist et al. (2001) documented high correlation of tag recoveries with the site of tag release so that complete mixing does not apply to at least one component of the body of fish tagged.

(2) *Population tagged is not closed*. An assumption of standard tagging models is that the population marked is closed, so that emigration or immigration of fish is not incorrectly interpreted as mortality or recruitment, respectively. The northern B.C. stock, in particular, is not considered a closed population due to exchange of fish with Alaska (see McFarlane and Beamish 1983, 1988, McFarlane and Saunders 1997, Kimura et al.

1998, Haist et al. 1999b). The strong monthly effect demonstrated by the monthly tagging model (Kronlund et al. 2003) lends support to this view. Thus, the possibility of sablefish abundance in northern B.C. being influenced by fluctuations in the much larger Alaskan sablefish stock means that movement into or out of B.C. waters should be accounted for in model design.

(3) *Definition of the population tagged*. Haist et al. (2001) argued that since the tags were applied primarily at the same depths where most commercial fishing was conducted, the estimated exploitation rates applied to the trap vulnerable population rather than the entire sablefish population. The exploitation rates of the entire sablefish population would therefore be lower than the model estimates, since biomass estimate represented only the trap vulnerable portion of the population.

These considerations have motivated investigation of an alternative to the monthly tagging model utilized by Kronlund et al. (2003) and presented here.

H.2 Tag reporting rates

Tag recovery rates represent the combined effects of tag-induced mortality, tag shedding, exploitation, and tag reporting. The effect of movement into or out of the waters covered by the tagging survey is also reflected in tag recovery rates for British Columbia. If tag-induced mortality, tag shedding, and movement can be quantified, then the tag recovery rate is itself the product of the exploitation rate and the probability that a tag on a harvested fish will be recovered, i.e., the tag reporting rate (Pollock et al. 2002). Tag reporting rates have the effect of scaling the biomass and exploitation rate estimates derived from a model to account for tagged fish that were recovered but not reported. A lower tag reporting rate implies a larger inflation of observed tags to account for unreported tags.

Estimation of tag reporting rate is problematic, and various approaches have been employed including the use of tagging data alone (e.g., sablefish), surreptitiously planted tags, surveys of fishermen, high-reward tagging, and catch data from multiple-component fisheries (Pollack et al. 2001, 2002). For high-reward tagging, the incentives for returning “high-reward” tags are assumed to result in 100 percent reporting rates. The reporting rate of standard tags is estimated using the ratio of the recovery rate of standard tags to the recovery rate of high-reward tags. For multiple- component fisheries, all tags are assumed to be returned by one component of the fishery, say those vessels that carry at-sea observers. Reporting rates in other fishery components are scaled in a manner similar to the high-reward situation with reference to the 100 percent reporting fishery component. In Alaska, tag reporting rates have been estimated by comparing tag returns in the fishery to tag returns from longline surveys where all tags were assumed to be reported (Heifetz and Maloney 2001).

The data available for sablefish in B.C. include the total tonnes landed, and the total tags returned by vessel, month, year and area (north or south). There is a single tag type with no difference among incentives offered for tag returns. The fishery does not have a history of representative deployment of at-sea observers, so there is no fishery component that could be regarded as 100 percent reporting. The fishery is not amenable to surreptitious planting of tags. Finally, the tags have been applied at consistent release localities since 1991 (Appendix G) so that survey sets have a higher probability of tag recovery than commercial fishery sets (Table 9 in Haist et al. 2001) and thus survey recovery rates cannot be used as a reference. Thus, any estimation of tag reporting rates must involve *ad hoc* assumptions. Note, however, that the implementation of randomly distributed tagging sets in 2003 (Appendix G) that use gear and baiting similar to commercial trap fishing offers the potential of using the tagging survey as a 100 percent reporting rate reference group in the future.

In 1999, Hilborn and Pascual (*In* Haist et al. 1999b) derived annual tag reporting rates for trap gear by comparing the tags recovered per tonne of landed fish among vessels standardized for month, year, and area. The analysis, which was updated in 2003 (Kronlund et al. 2003), assumed that differences in tags per tonne landed among vessels could be assigned to differences in tag reporting rates (Table H.1). A reference group of vessels was selected and assumed to be 100 percent reporting. Tags per tonne landed for other vessels were compared to the reference group to determine relative reporting rates. However, there may be no relationship between the reporting of tags and the tags per tonne landed. For example, tags per tonne landed in B.C. are related to the number of tags at large (Appendix G). Recent analyses of recoveries for particular tag release groups showed that vessel fishing patterns may be more important in determining tags per tonne than the diligence of a vessel crew in reporting tags (Haist et al. 2001), i.e., fishing near tag release sites significantly raises the probability of recovering tags. Seasonal effects may also influence the tags per tonne landed independently of the diligence of the vessel crew in reporting tags. These observations suggested that assumptions of previous reporting rate analyses are not as acceptable as when first proposed. As an alternative, the new tagging model integrates reporting rates as stochastic variables in a Bayesian framework to allow the data to indicate whether there is information on reporting rates.

H.3 New Tagging Model

Model description

Table H.2 presents notation for a new tagging model for B.C. sablefish. The model described in Table H.3 includes population dynamics equations (T.2)-(T.5) for the numbers of fish in each month m of recovery year y. Tag dynamics for the number of tags alive in each month and year from tag release year g are listed in equations (T.11)-(T.13). The new model has the following structural characteristics:

1. Tag recoveries can be utilized regardless of the number of years at large, rather than limiting data to tags recovered in the year following release, as was the practice for the deterministic and monthly tagging models;

2. Tags recovered in December through March are not included in the model fit to accommodate the significant decrease in tags per tonne landed that typically occurs during this period;
3. New untagged fish enter the trap vulnerable biomass through recruitment or immigration in the first month of each year,
4. Fish, both tagged and untagged, are permitted to leave the trap vulnerable biomass each month;
5. Tag reporting rates are treated as stochastic variables rather than fixed inputs, in contrast to the deterministic and monthly tagging models;
6. As was the case for previous tagging models, adjustments are made for initial tag loss due to tag shedding and tag induced mortality in the period between tag application and recovery in year g+1.

Model parameters listed in equation (T.1) include the number of fish alive at the beginning of the analysis, $\exp(\alpha)$, the numbers of fish entering the population each year, $\exp(\gamma_y)$, and the monthly fraction of fish retained in B.C., ν.

The population dynamics are initialized by equation (T.2) for month M_1 of year Y_1, here January of 1992. Equation (T.3) relates the number of fish alive in January of the current year to the number alive in December, M_2, of the previous year. The number of fish N_{y-1,M_2} is reduced by monthly natural mortality, movement of fish to non-vulnerable areas, and fishing mortality. For the first month of the year, the population is increased by $\exp(\gamma_y)$ fish entering the population through recruitment or immigration from areas not vulnerable to B.C. trap fishing. The last year, Y_2, of the population dynamics for January is specified by equation (T.4), which is identical to (T.3) except no new fish enter the population. Since no January to March data are being fit for year Y_2=2003, there is no means of estimating a γ_{2003}. For all other months and years, equation (T.5) updates the population numbers N_{ym}, correcting for monthly natural mortality, movement to non-vulnerable areas, and fishing mortality.

Total biomass of landings, D_{kym}, in each month and year from the north or south stock areas enter the model as data. Landings biomass is converted to numbers of fish landed by equation (T.6) for total landings and by equation (T.7) for sablefish trap fishery landings. The exploitation rate due to all sources of removals, u_{ym}, is calculated by equation (T.8). Similarly, equation (T.9) specifies the exploitation rate due to sablefish trap fishing, u^*_{ym}.

Population biomass is computed as an output quantity for each month and year by use of equation (T.10), which expresses biomass as the product of the number of fish in the population N_{ym} and the mean weight of vulnerable fish, $\overline{w}^V_y$.

Tag dynamics are described by equations (T.11)-(T.13). The number of tags alive in month M_1 for each year after release, $y = g + 1$, is defined in equation (T.11). The tags released in year *g* are reduced by the initial tagging loss due to tag shedding and tagging induced mortality. For months after M_1, the tags alive in the current month and year from a release group are related to the tags alive in the previous month by equation (T.12). As for the untagged population, tagged fish are lost due to natural mortality, movement of tagged fish to non-vulnerable areas, and fishing mortality. In addition, the tag shedding parameter, *s*, is supplied to the model as a fixed parameter. Finally, the tags alive in month M_1 of year *y* are related to those alive in month M_2 of the previous year by equation (T.13) after adjustment for sources of mortality and movement.

The number of tags predicted in the trap fishery for month *m*, year *y* and release year *g* is

$$P_{ym}^{g} = T_{ym}^{g} u_{ym}^{*} \omega_y c_{ym} \quad .$$

This equation states that the number of tags alive in population is adjusted by the trap fishery exploitation rate, u_{ym}^{*}, the tag reporting rates, ω_y, and sorting factors, c_{ym}. The sorting factors adjust for retention of small tagged fish that would otherwise be released and for the inception of escape rings in 1999 as described below.

A Bayesian approach (Gelman et al. 1995) was used to render the model described in Table H.3 statistical and thereby derive the posterior distribution of the parameters given the data. This approach allowed the distribution of the reporting rates to be estimated while recognizing the considerable uncertainty associated with these estimates. The following prior distributions were specified for the model parameters, where *U* and *N* denote the Uniform and Normal statistical distributions, respectively:

$$\alpha \sim U\left[0, \alpha\right] \quad ,$$
$$\gamma_y \sim U\left[1, \alpha\right] \quad ,$$
$$\omega_y \sim U\left[0.3, 0.95\right] \; or \; \omega_y \sim N\left[\widetilde{\omega_y}, \sigma_\omega^2\right] \quad \text{, and}$$
$$\nu \sim U\left[0.95, 1.0\right] \quad .$$

The reporting rates parameters, ω_y, were specified with both an uninformative Uniform prior (Case 1), and an informative Normal prior (Case 2) with means $\widetilde{\omega_y}$ set to the reporting rates provided in the most recent stock assessment (Kronlund et al. 2003).

In Bayesian analysis the objective function is defined as a negative log-posterior

$$Objective\left(\Theta\right) = -\sum_i \log\left(L\left(\Theta \mid O_i\right)\right) - \log\left(\pi\left(\Theta\right)\right) \quad ,$$

where Θ is the vector of free parameters, L, is the likelihood function, O_i is observation i, and π is the joint prior density of parameters, Θ. An over-dispersed Poisson distribution is assumed for the tag recovery data. For a standard Poisson distribution the variance of a random variable is equal to its expectation. Like many fisheries tagging data sets, the residuals from model fits to the sablefish tag-recovery data are much larger than expected from sampling theory since the model does not account for the entire process underlying the data. Therefore, a scalar variable, d, is included in the objective function to account for the higher variance of the observations. This is effectively the same as reducing the actual sample sizes (number of tags released and resultant recoveries). Ignoring constants, the negative log-likelihood for the data observations is

$$-\log\left(L\left(\Theta \mid O_{ym}^{g}\right)\right) = d\sum_{g=G_1}^{G_2}\sum_{y=g+1}^{Y_2}\sum_{m=4}^{11}\left\{P_{ym}^{g} - O_{ym}^{g}\log\left(dP_{ym}^{g}\right)\right\} \quad .$$

Note that the January to March data are not included in the summation over m. The value of d used in the final analysis was determined through an iterative process. The distributions of Pearson residuals (described below) were examined for alternative values of d. The value that resulted in a distribution of Pearson residuals that was approximately standard normal was selected. Closeness to standard normal was judged relative to two measures: (1) a value of 1 for the variance of the residuals, and (2) a measure more robust to outliers, the median of the absolute residuals (expected value of 0.68). On this basis, a value of 0.15 was selected for d. Pearson residuals were calculated as

$$r_{ym}^{g} = \frac{dO_{ym}^{g} - dP_{ym}^{g}}{\sqrt{dP_{ym}^{g}}} = \frac{O_{ym}^{g} - P_{ym}^{g}}{\sqrt{P_{ym}^{g}/d}} \quad .$$

Prior distributions that are uniform do not contribute to the negative log posterior. However, when the informative Normal prior is specified for the reporting rates the prior density is not constant and the term

$$-\log\left(\pi\left(\Theta\right)\right) = 0.5\left(\frac{\log\left(\omega_y/\widetilde{\omega_y}\right)}{\sigma_\omega}\right)^2 \quad ,$$

is added to the negative log posterior. Constants involving only data are ignored in the prior, and the standard deviation term was set to $\sigma_\omega = 0.2$ for this analysis.

Details of fixed parameters

Various parameters used in the tagging analysis were derived externally to the model and input as fixed parameters.

Natural mortality. The instantaneous rate of natural mortality was assumed to be M=0.08, which is between the value of 0.07 assumed for the continental U.S. assessment (Schirripa 2002) and the value of 0.107 estimated by Sigler et al. (2003) for Gulf of Alaska sablefish. This assumption implies a monthly survival rate of $a = \exp\left(-0.08/12\right) = 0.993$.

Tag loss. Beamish and McFarlane (1988) estimated tag loss at 10 percent over the first year, and two percent thereafter, based on data from sablefish tagged with one Floy anchor tag and one suture tag and for data collected until 1985. Lenarz and Shaw (1997) analyzed U.S. sablefish recovery data from double-tagged fish and estimated tag loss in the first year to be 5 percent and instantaneous tag shedding rates of 0.03 and 0.069 for Floy anchor tags positioned anterior and posterior to the first dorsal fin, respectively. Appendix D in Haist and Hilborn (2000) examined a data set similar to that used by Beamish and McFarlane (1988) and estimated an initial tag loss rate of 0.0416 and a subsequent instantaneous loss rate of 0.0366, which are the estimates used here.

Tag application typically occurred in mid-October, meaning that about 2.5 months elapsed prior to the start of the next year. The rate of tag loss over this period is about $1-\exp\left\{-0.0366\left(2.5/12\right)\right\} = 0.007625$. Thus, the rate of tag survival after tagging induced mortality, initial tag loss and tag shedding in the interval between tag application and year y=g+1 was fixed at $l = 1-\left\{0.0951+0.0416+0.007625\right\} = 0.856$. The fraction of fish retaining tags in each month is given by $s = \exp\left(-0.0366/12\right) = 0.997$.

Sorting factors. Adjustment for the number fish inspected for tags is required because fishermen release some smaller sablefish except when the fish is tagged. Additionally, the adoption of escape rings by the sablefish trap fishery impacted the size frequency, and therefore the mean weight, of sablefish captured. The change in size frequency altered the number of fish sampled for tags relative to the number landed and the conversion of biomass landed to numbers landed. Appendix C in Haist and Hilborn (2000) was an analysis of data from an escape ring study designed to estimate the ratio of the number of fish sorted to numbers landed. The study compared the performance of trap gear fitted with 3 1/2 and 3 7/8 inch escape rings to control traps without escape rings at different locations and for various soak times (Saunders and Surry 1998). The number of fish landed per metric tonne pre and post inception of escape rings was estimated by north and south stock areas, and for shallow, medium, and deep depth strata. The number of fish sampled per metric ton landed with, and without, escape rings was estimated from observer data collected in 1992 and 1993 by Haist et al. (1999b) for the same stratification. This analysis was updated for 2003 for the medium depth stratum of the north and south stock areas using data from an escape ring study completed in 2001 (Appendix N, Table H.1).

The sorting factors are expressed in terms of the number of fish sampled for tags by the number of fish landed, in order to correct for retention of small tagged sablefish that would otherwise be released. The area and year specific sorting ratios, R_{ky}, for 2003 (Table H.1) were used to compute sorting factors for each year and month as

$$c_{ym} = \left(\sum_{k=1}^{K} D_{kym}^{*} \frac{1}{\overline{w}_{ky}^{L}} \left(1 + \mathrm{R}_{ky}\right) \right) \Big/ C_{ym}^{*} \quad .$$

Mean fish weight. Data from the standardized survey were used to compute the mean weights of vulnerable fish, $\overline{w}_y^V$. For each standardized survey set conducted in depth strata 1 through 5, a ratio estimate of mean weight was calculated by dividing the total weight of fish captured by the total number of fish captured. The annual mean weight was determined by taking the mean of the ratio estimates of mean fish weight by set and year (Table H.1). The mean weights of landed fish, $\overline{w}_y^L$, were determined by analysis of the 2001 escape ring data (Appendix N) and are provided for the south and north stock areas pre and post inception of escape rings in the fishery (Table H.1).

Data selection

Tag recovery data used in the model analysis were obtained from adult offshore releases and recoveries as described in Appendix G. Tag recoveries were included without regard to the years at large. Tag recoveries in the period between tag application in year *g* and the start of year recovery year *y*=*g*+1 were not included.

Model results

The new tagging model was implemented using the AD-Model Builder software package which provides for Markov Chain Monte Carlo (MCMC) estimation of the Bayesian posterior density (Otter Research 1999). This software package uses a MCMC method based on the Metropolis-Hastings algorithm (Gelman et al. 1995) to obtain samples from the full posterior distribution.

As the time at large increases, the tag recoveries become sparse in the combinations of recovery year and month for a given release year. The negative log likelihood function was modified to allow collection of tag recoveries into an accumulator class after *t* years at large for each release year

$$-\log\left(L\left(\Theta \mid O_{ym}^{g}\right)\right) = d \sum_{g=G_1}^{G_2} \left\{ \sum_{y=g+1}^{T} \sum_{m=4}^{11} \left\{ P_{ym}^{g} - O_{ym}^{g} \log\left(dP_{ym}^{g}\right) \right\} + \left\{ P_{\bullet\bullet}^{g} - O_{\bullet\bullet}^{g} \log\left(dP_{\bullet\bullet}^{g}\right) \right\} \right\} \;,$$

where $T = \min\left(g + t, Y_2\right)$, *t* is the number of years of tag recoveries fit before the accumulator category, and the dot notation indicates summation over indices $y = T+1,\ldots,Y_2$ and $m = 4,\ldots,11$, respectively. Experimentation with various values suggested *t*=6 was a parsimonious choice.

The structural behavior of the model is shown in Figure H.1 for the maximum posterior density (MPD) estimates for Case 1. The purpose of the figure is to illustrate features of the model, such as the addition of fish each January through recruitment and immigration allowed by the γ_y (upper panel) which produces the saw-tooth pattern in the biomass trend. The lower panel of Figure H.1 shows annual biomass trends for the start of January biomass, $B_{y,1}$, mean monthly biomass, and start of December biomass, $B_{y,12}$.

Figure H.2 and Figure H.3 show model results for Case 1 and 2, respectively. The marginal posterior distributions of $B_{y,1}$, $\exp(\gamma_y)$, and ω_y are summarized using quantile plots. The distributions are based on an MCMC sample of size 2000 taken systematically from a chain of length 250 million for Case 1 (uninformative prior) and 100 million for Case 2 (informative prior). The quantile plots are constructed such that the lower and upper whiskers represent the 10th and 90th percentiles of the distributions, while the box shows the 25th, 50th, and 75th percentiles. The filled circles indicate the MPD estimates for each parameter and year. Uncertainty is greatest for January biomass (upper panel, both cases) in 1992 and 1993, and decreases thereafter as the number of tag release groups being fit increases. For most years the MPD estimates are near the lower limits of their posterior distributions. The posterior distributions suggest that the biomass was potentially larger for 1992 to 1994 than indicated by the MDP estimates, although with relatively greater uncertainty than exists after 1994. Figure H.4 shows densities of January biomass by year for the same MCMC sample portrayed in Figure H.2 for Case 1. Quantiles shown in the plots of Figure H.2 are indicated as vertical lines in the panels of Figure H.4. Summary statistics of the marginal posterior distribution for January biomass are listed in Table H.4 for both cases.

The quantile plots for γ_y (centre panels) show a peculiar two year cycle beginning in 1996 for Case 1 (Figure H.2) that does not occur in the plots for Case 2 (Figure H.3). The distributions of reporting rate parameters (lower panel) for Case 1 show little similarity to those obtained by external analysis in 2002 (Table H.1). When the informative Normal prior is applied for Case 2, the trend in reporting rates distributions is similar to the 2002 values, as expected. For both cases, however, the distribution of 2001 reporting rates is considerably lower than the values from the external analysis. There is no reason to believe that reporting rates were much reduced in 2001, which suggests that the parameter is aliasing for factors not included in the model.

Plots of the MCMC chains for $B_{y,1}$, γ_y, and ω_y corresponding to 1993, 1996, 1999, and 2002 are shown in Figure H.5 (Case 1) and Figure H.6 (Case 2). The plots suggest that the MCMC has not converged to the posterior parameter distribution, and therefore a much longer chain than 250 million is warranted but could not be completed due to computation time constraints. Some parameters show extremely high autocorrelation in the traces, in particular the Case 1 γ_y plots for 1993, 1995, 1996, 1998, 2000 and 2002 (1995, 1998, 2000 not shown). These years correspond to large additions of fish to the January biomass via the γ_y. However, the January biomass parameters used to derive a stock index do not show patterns as extreme as those for γ_y and thus the lack of full convergence is unlikely to affect the quantities of primary importance.

H.4 Comparison to previous tagging model results

Results for the deterministic and monthly tagging models were originally presented without uncertainty. The Bayesian implementation of the new tagging model means that direct comparison with previous tagging models is not possible since the posterior distribution is not a point estimate. However, a simple evaluation can be made by comparing the Case 1 MPD estimates of trap vulnerable biomass to three additional cases:

1. *Case 3*: Deterministic model, reporting rates from 2002, sorting factors from 2003, and 12 months of tag recoveries;
2. *Case 4*: Deterministic model, reporting rates from 2002, sorting factors from 2003, and tag recoveries for April through November. The month restriction on tag recovery data implies that only trap landings and total landings for the April through November period were included for this case;
3. *Case 5*: Monthly tagging model, reporting rates from 2002, sorting factors from 2003.

The deterministic model provided estimates of beginning of year trap vulnerable biomass. For the monthly tagging model, the parameters estimated by the model were the trap vulnerable biomass alive in the first month of each year, along with the month effects. The trajectories of estimated vulnerable biomass for each case are shown in Figure H.7. Trajectories for the deterministic, monthly and Case 1 MPD estimates are similar. The monthly tagging model departed from the other cases by compensating for a relatively low rate of tag recoveries in late 2002 by increasing biomass. Removal of December through March data had the effect of smoothing the deterministic trajectory and eliminating a peak biomass in 1999, as occurred for the Case 1 results.

H.5 Summary

Results from Case 1, where an uninformative prior distribution was specified for the reporting rates, indicated little similarity between previous reporting rate estimates and those estimated by the model. Furthermore, patterns in posterior distributions of the ω_y suggested that some of these parameters were aliasing for factors not included in the model. On this basis, the Case 1 configuration of the model was preferred.

The new tagging model is based on the hypothesis that the trap vulnerable B.C. sablefish stock is open to immigration and emigration. This movement may occur within B.C. and also as a result of exchange of fish with seamounts, Alaska or continental U.S. waters. Evidence based on annual and seasonal patterns in catch rates and tags per tonne landed suggested influx of fish to the stock in the December to March period. These patterns were accommodated by fitting tag recovery data from April to November. This is a compromise, however, and it would be useful to incorporate data from outside the

B.C. stock area to evaluate whether estimation of the population and tagging dynamics could be improved.

H.6 Literature Cited

Beamish, R.J. and G.A. McFarlane. 1983. Summary of results of the Canadian sablefish tagging program. p. 147-183. *In* Proceedings of the Second Lowell Wakefield Fisheries Symposium. Anchorage, AK. Alaska Sea Grant Report 83-8.

Beamish, R.J. and G.A. McFarlane. 1988. Resident and dispersal behavior of adult sablefish (*Anoplopoma fimbria*) in the slope waters off Canada's west coast. Can. J. Fish. Aquat. Sci. **45**: 152-164.

Gelman, A.B.; Carlin, J.S.; Stern, H.S.; Rubin, D.B. (1995): Bayesian data analysis. Chapman & Hall, London. 526 p.

Haist, V., Saunders, M.W., Hilborn, R., and M. Maunder. 1997. Sablefish stock assessment for 1997 and recommended yield options for 1998. Can. Stock Assess. Sec. Res. Doc. 97/146.

Haist, V., Fournier, D., and M.W. Saunders. 1999a. Reconstruction of B.C. sablefish stocks, 1966-1998, and catch projections for 1999, using an integrated catch-age mark-recapture model with area and depth movement. Can. Stock Assess. Sec. Res. Doc. 99/79.

Haist, V., Hilborn, R., and M.W. Saunders. 1999b. Sablefish stock assessment for 1999 and recommended yield options for 2000 and 2001. Can. Stock Assess. Sec. Res. Doc. 99/195.

Haist, V. and R. Hilborn. 2000. Sablefish stock assessment for 2000 and recommended yield options for 2001. Can. Stock. Assess. Sec. Res. Doc. 2000/157. 78 p.

Haist, V., Hilborn, R., and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. Can. Sci. Advisory Res. Doc. 2001/135. 54 p.

Heifetz, J. and N.E. Maloney. 2001. Estimation of tag-reporting rates for sablefish in the northeastern Pacific Ocean. Alaska Fish. Res. Bull. 8(**1**):1-11.

Kimura, D.K., Shimade, A.M., and F.R. Shaw. 1998. Stock structure and movements of tagged sablefish, *Anoplopoma fimbria* in offshore northeastern Pacific waters and the effects of El Nino-southern oscillation on migration and growth. Fish. Bull. 96: 462-481.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

Kronlund, A.R., M. Wyeth, and R. Hilborn. 2002. Review of survey, commercial fishery, and tagging data for sablefish (*Anoplopoma fimbria*) in British Columbia: Supplement to the November 2001 sablefish stock assessment. Can. Sci. Adv. Sec. Res. Doc. 2002/074. 109 p.

Lenarz, W.H. and F.R. Shaw. 1997. Estimates of tag loss from double-tagged sablefish *Anoplopoma fimbria*. Fish. Bull. **95**: 293-299.

McFarlane, G.A. and M.W. Saunders. 1997. Dispersion of juvenile sablefish, *Anoplopoma fimbria*, as indicated by tagging in Canadian waters. *In* Biology and management of sablefish, *Anoplopoma fimbria*. p. 81-92. NOAA Technical Report NMFS 130.

Otter Research Ltd. 1999. AD Model Builder documentation on line. http://otter-rsch.com/admodel.htm.

Pollock, K.H., J.M. Hoenig, W.S. Hearn, and B. Calingaert. 2002. Tag reporting rate estimation: 2. Use of high-reward tagging and observers in multiple-component fisheries 22: 727-736.

Pollock, K.H., J.M. Hoenig, W.S. Hearn, and B. Calingaert. 2001. Tag reporting rate estimation: 1. An evaluation of the high-reward tagging method. N. Amer. J. Fish. Mgmt. 21: 521-532.

Saunders, M.W. and N. Surry. 1998. Preliminary results of blackcod escape ring study, F/V Ocean Pearl, November-December 1997. Report prepared for the Pacific Coast Blackcod Fisherman's Association.

Saunders, M.W., Leaman, B.M., Haist, V., Hilborn, R., and G.A. McFarlane. 1996. Sablefish stock assessment for 1996 and recommended yield options for 1997. PSARC Working Paper G96-5.

Schirripa, M.J. 2002. Status of the sablefish resource off the continental U.S. Pacific coast in 2002. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

Sigler, M.F., Lunsford, C.R., J.T. Fujioka and S.A. Lowe. 2003. Alaska sablefish assessment for 2003. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2004. November 2003, Plan Team Draft (http://www.afsc.noaa.gov/refm/stocks/assessments.htm).

Table H.1 Tag reporting rates, sorting ratios, and mean weight of landed and vulnerable sablefish by year, area and source. The sources for reporting rates are Kronlund et al. (2003) for "Coast 2002" and Haist et al. (1999) for "Coast 1999". Reporting rates in italics are assumed values. The sources for sorting ratios and mean weights are Appendix N for "2003" and Haist and Hilborn (2000) for "2000". Sorting ratios for 2000 were extracted from the "mid" depth stratum by area.

	Reporting Rates		Sorting Ratio (R_y)				Mean Wgt. Vulnerable (kg)			Mean Wgt Landed (kg)			
Year	Coast 2002	Coast 1999	South 2003 R_{1y}	North 2003 R_{2y}	South 2000 R_{1y}	North 2000 R_{2y}	South $\bar{w}^V_{1y}$	North $\bar{w}^V_{2y}$	Coast $\bar{w}^V_{y}$	South 2003 $\bar{w}^L_{1y}$	North 2003 $\bar{w}^L_{2y}$	South 2000 $\bar{w}^L_{1y}$	North 2000 $\bar{w}^L_{2y}$
1992	0.42	0.39	1.02	0.50	1.02	0.50	2.68	3.27	2.904	3.63	4.00	3.63	4.00
1993	0.40	0.37	.	.	.	.	.	.	3.151	.	.	.	.
1994	0.47	0.53	.	.	.	.	.	.	3.390	.	.	.	.
1995	0.70	0.76	.	.	.	.	.	.	3.137	.	.	.	.
1996	0.66	0.74	.	.	.	.	.	.	3.345	.	.	.	.
1997	0.54	***0.75***	.	.	.	.	.	.	3.469	.	.	.	.
1998	0.53	***0.75***	1.02	0.50	1.02	0.50	.	.	3.043	3.63	4.00	3.63	4.00
1999	0.74	***0.75***	0.32	0.16	0.52	0.25	.	.	3.417	3.89	4.22	3.85	4.22
2000	0.63	***0.75***	.	.	.	.	.	.	3.090	.	.	.	.
2001	0.73	***0.75***	.	.	.	.	.	.	2.985	.	.	.	.
2002	0.92	***0.75***	.	.	.	.	.	.	2.770	.	.	.	.
2003	***0.92***	***0.75***	0.32	0.16	0.52	0.25	2.68	3.27	2.906	3.89	4.22	3.85	4.22
2004	-	-	-	-	-	-	-	-	2.902	-	-	-	

Table H.2 Notation for the new sablefish tagging model.

Symbol	Description
	Indices and Index Ranges
g	Release year index, $g = G_1, \ldots, G_2$, where $G_1 = 1991, G_2 = 2002$.
y	Recovery year index $y = Y_1, \ldots, Y_2$, where $Y_1 = 1992, Y_2 = 2003$.
m	Month index for recovery year $y \left(m = M_1, \ldots, M_2 \right)$.
k	Area index $\left(k = 1, \ldots, K \right)$
	Data
D_{kym}	Total landed biomass in month *m* of year *y* for area *k*.
D^*_{kym}	Trap landed biomass in month *m* of year *y* for area *k*.
$\bar{w}^L_{ky}$	Mean weight of landed fish in year *y* for area *k*.
$\bar{w}^V_y$	Mean weight of trap vulnerable fish in year *y*.
c_{ky}	Ratio of number of fish caught to number landed for recovery year *y* in area *k*.
R^g	Number of "traditional" tag releases in release year *g*.
O^g_{ym}	Observed tag recoveries from trap gear in month *m*, year *y*, release group *g*.
	Fixed Parameters
M	Instantaneous rate of natural mortality.
a	Monthly survival from natural mortality.
l	Tag survival rate after initial tag shedding, tagging mortality.
s	Fraction of fish retaining tags each month.
	Estimated Parameters
α	Number of fish in B.C. in the first recovery year, Y_1, and month, M_1.
γ_y	New fish in year *y* due to recruitment or immigration into B.C.
ω_y	Reporting rate in year *y*.
ν	Monthly fraction of the number of fish retained in B.C.
Θ	Parameter vector
	Derived Parameters
N_{ym}	Total number of fish in month *m* of year *y*.
B_{ym}	Biomass of fish in month *m* of year *y*.
C_{ym}	Total catch numbers in month *m* of year *y*.
C^*_{ym}	Total trap catch numbers in month *m* of year *y*.
u_{ym}	Exploitation rate for month *m* of recovery year *y*.
u^*_{ym}	Exploitation rate by trap gear for month *m* of recovery year *y*.
T^g_{ym}	Tags alive in month *m* of recovery year *y*, that were released in year *g*.
P^g_{ym}	Predicted tag recoveries for release year *g*, in month *m* of recovery year *y*.

Table H.3 Population and tag dynamics for the new sablefish tagging model.

Parameters

(T.1) $\Theta = \left(\alpha, \gamma_y, \omega_y, \nu\right)$

Population Dynamics

$\left(y = Y_1, \ldots, Y_2;\; m = M_1 + 1, \ldots, M_2\right)$

(T.2) $N_{Y_1,M_1} = \exp(\alpha)$

(T.3) $N_{y,M_1} = N_{y-1,M_2} a\nu\left(1 - u_{y-1,M_2}\right) + \exp\left(\gamma_y\right) \qquad Y_1 < y < Y_2$

(T.4) $N_{y,M_1} = N_{y-1,M_2} a\nu\left(1 - u_{y-1,M_2}\right) \qquad y = Y_2$

(T.5) $N_{ym} = N_{y,m-1} a\nu\left(1 - u_{y,m-1}\right)$

(T.6) $C_{ym} = \sum_{k=1}^{K} \frac{D_{kym}}{\overline{w}_{ky}^{L}}$

(T.7) $C_{ym}^{*} = \sum_{k=1}^{K} \frac{D_{kym}^{*}}{\overline{w}_{ky}^{L}}$

(T.8) $u_{ym} = \frac{C_{ym}}{N_{ym}}$

(T.9) $u_{ym}^{*} = \frac{C_{ym}^{*}}{N_{ym}}$

(T.10) $B_{ym} = N_{ym} \overline{w}_{y}^{V}$

Tag Dynamics

$\left(g = G_1, \ldots, G_2;\; y = g + 1, \ldots Y_2;\; m = M_1, \ldots, M_2\right)$

(T.11) $T_{y,M_1}^{g} = R^{g} l \qquad y = g + 1$

(T.12) $T_{ym}^{g} = T_{y,m-1}^{g} as\nu\left(1 - u_{y,m-1}\right) \qquad m > M_1$

(T.13) $T_{y,M_1}^{g} = T_{y-1,M_2}^{g} as\nu\left(1 - u_{y-1,M_2}\right)$

Table H.4 Summary statistics of the marginal posterior distribution for January biomass (t).

	Case 1: Uninformative Prior		**Case 2**: Informative Prior	
Year	**Mean**	**Median**	**Mean**	**Median**
1992	105026	97324	106339	105118
1993	125336	125042	109310	107619
1994	92599	92865	84532	83857
1995	59720	59597	59200	58424
1996	57334	55930	54069	52863
1997	40614	40671	39542	39260
1998	36407	35868	30030	28829
1999	24665	24292	26005	25450
2000	25826	25501	25977	25815
2001	14948	14690	16774	16186
2002	16574	16219	22574	22697

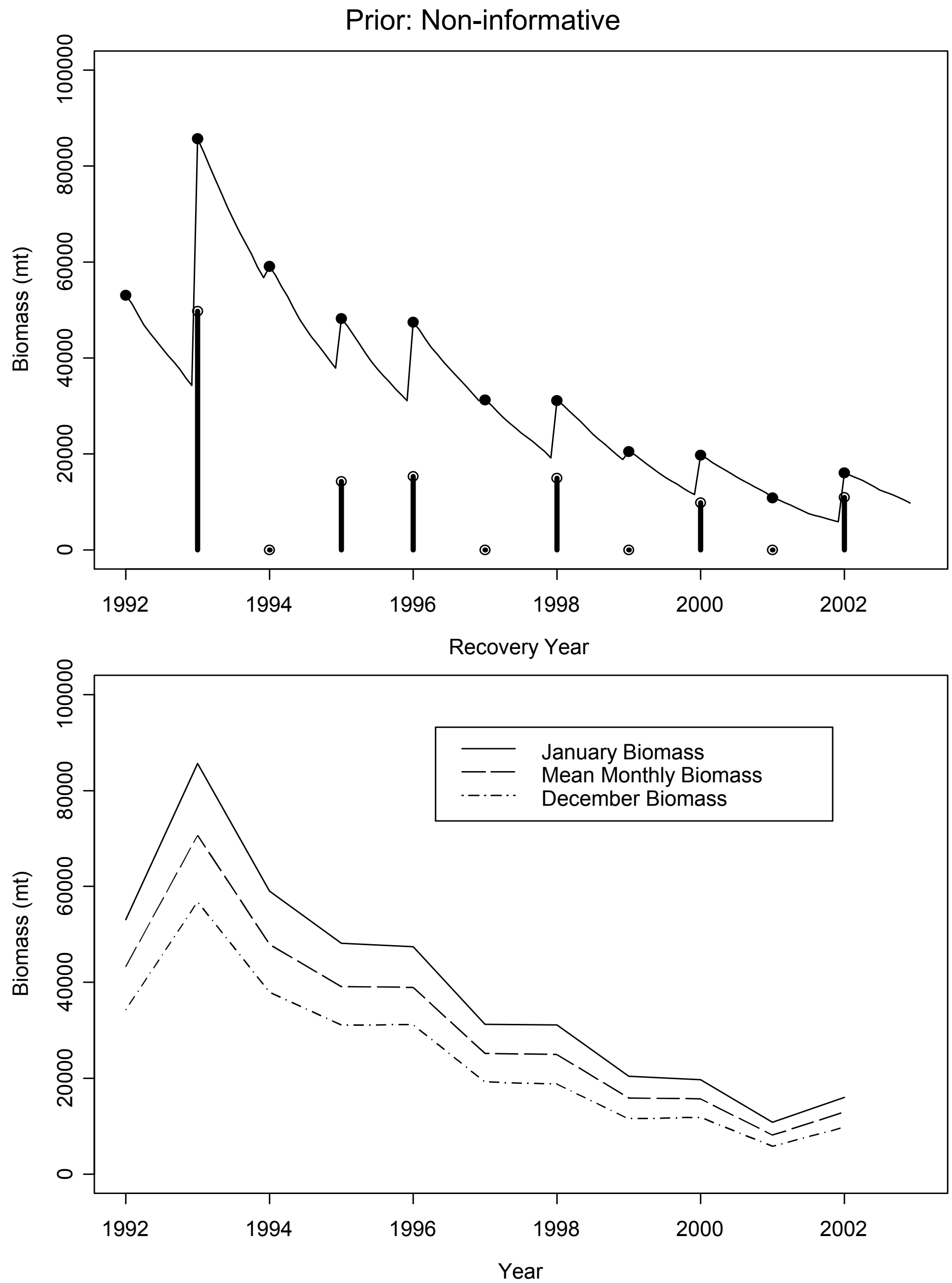


Figure H.1 Structure of the new tagging model. The upper panel shows the contributions of recruitment and immigration (vertical lines, open circles) to the biomass (solid line). The start of January biomass is shown as filled circles. The lower panel shows the biomass trend for start of January, the mean monthly biomass, and the start of December biomass. All estimates correspond to the maximum posterior density.

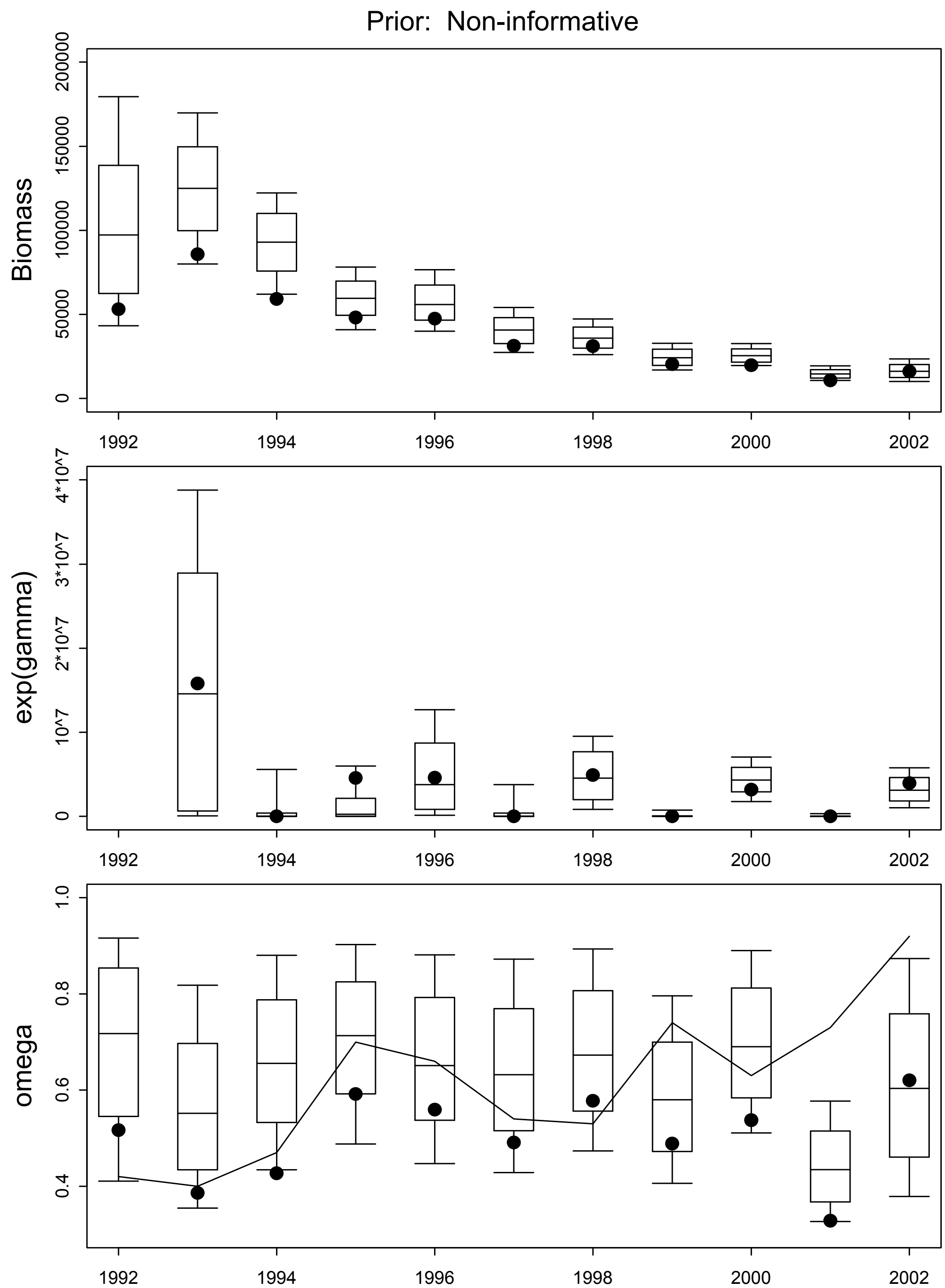


Figure H.2 Quantile plots of the Case 1 marginal posterior distributions of $B_{y,1}$, $\exp\left(\gamma_y\right)$, and ω_y based on a sample of size 2000 taken systematically from a chain of length 250 million. The filled circles are the MPD estimates. The solid line in the lower panel shows the 2002 reporting rate estimates.

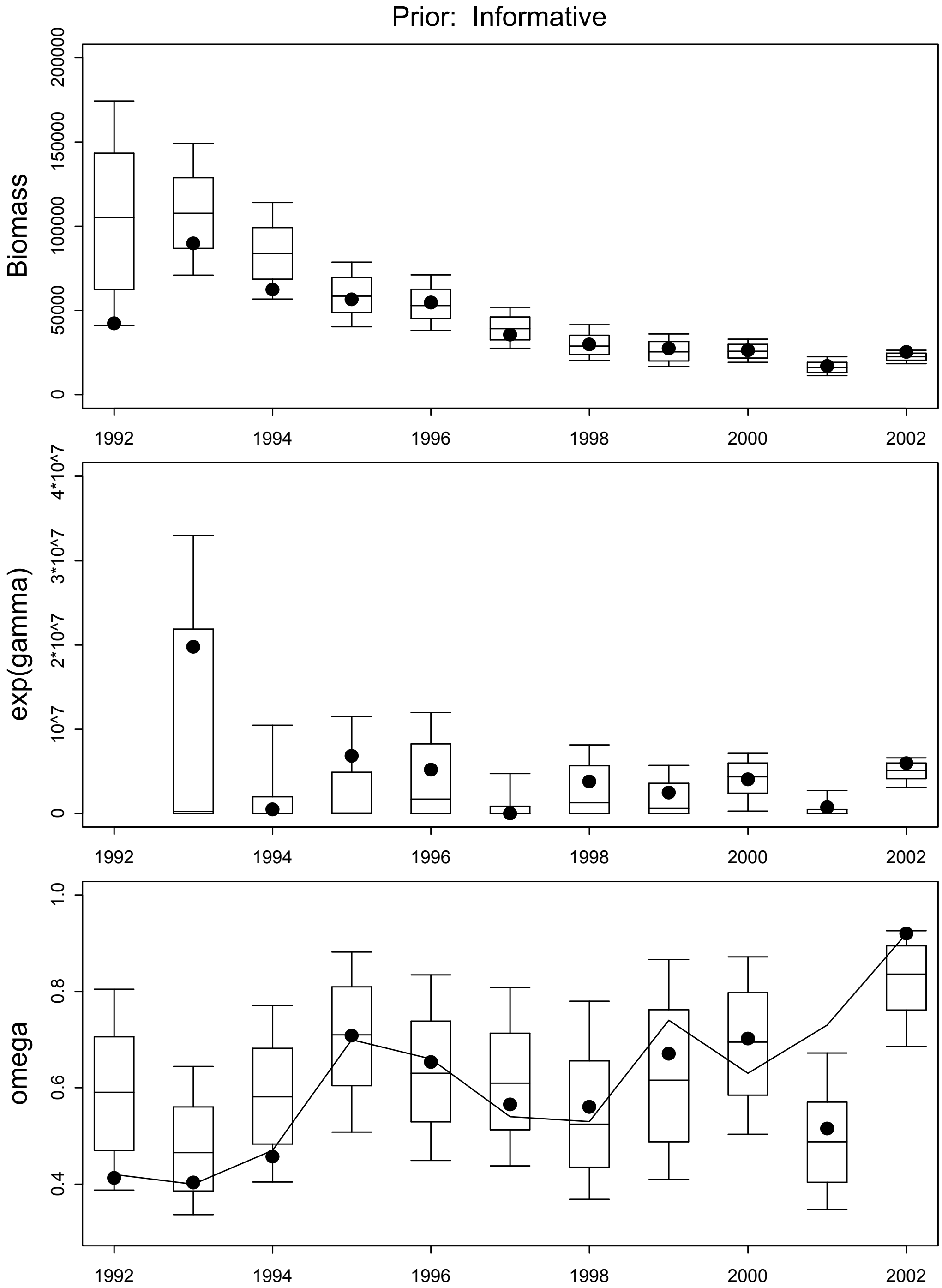


Figure H.3 Quantile plots of the Case 2 marginal posterior distributions of $B_{y,1}$, $\exp(\gamma_y)$, and ω_y based on a sample of size 2000 taken systematically from a chain of length 100 million. The filled circles are the MPD estimates. The solid line in the lower panel shows the 2002 reporting rate estimates.

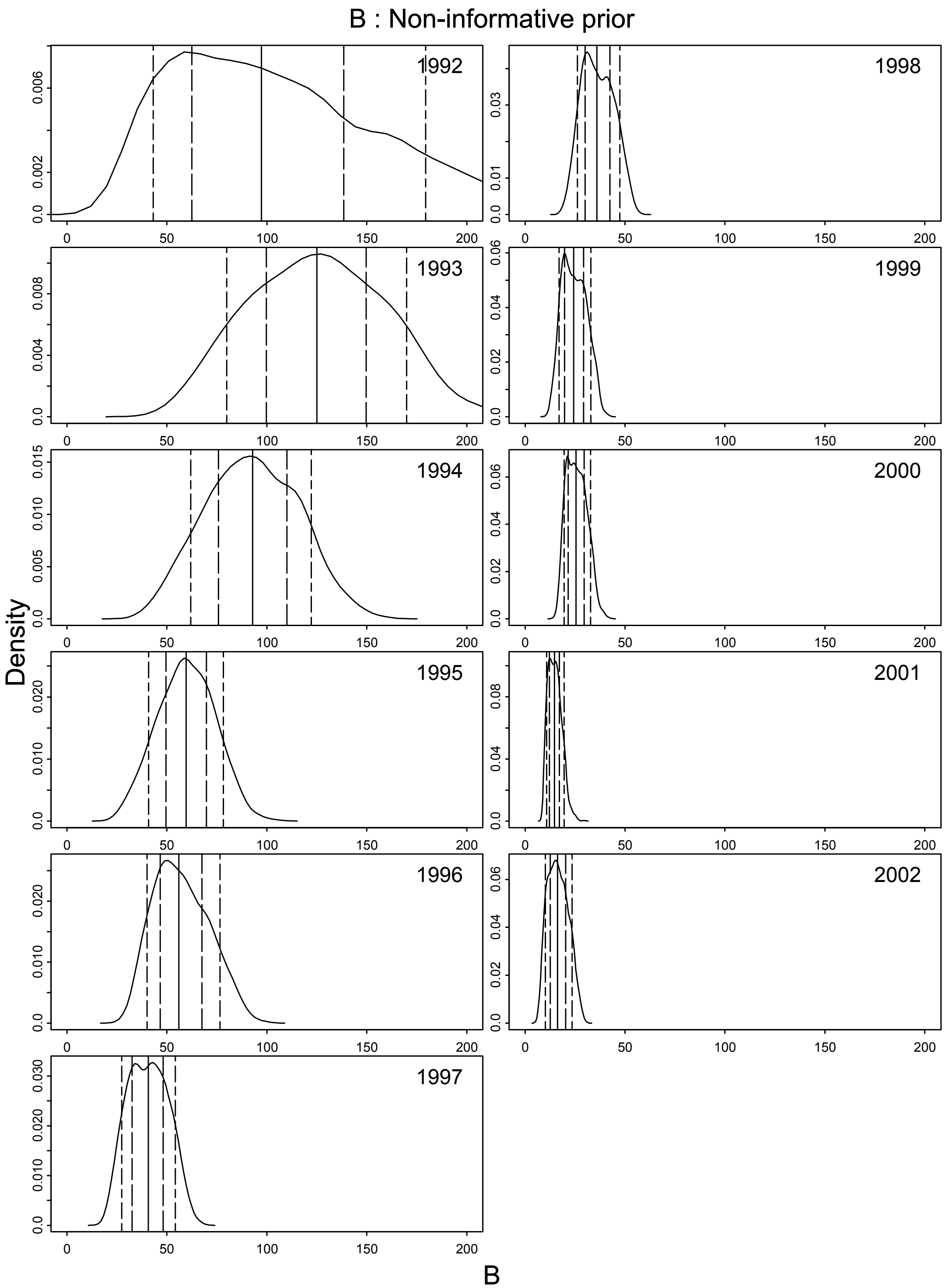


Figure H.4 Densities of $B_{y,1}$ (Case 1) for each year from an MCMC sample of size 2000 taken systematically from a chain of length 250 million. The vertical lines represent the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles of the distributions.

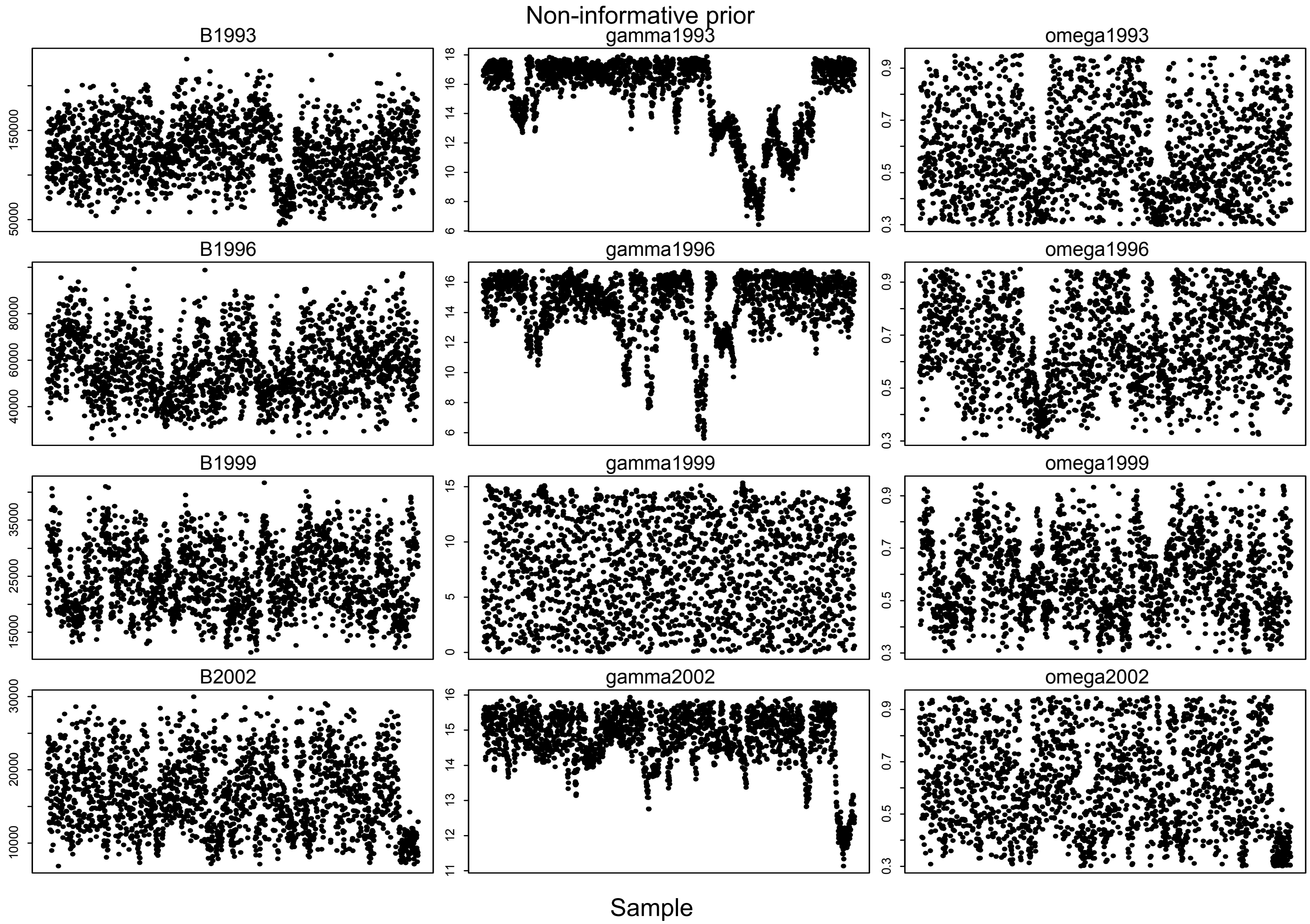


Figure H.5 Selected Case 1 MCMC chains for $B_{y,1}$, $\exp\left(\gamma_y\right)$, and ω_y. A sample of 2000 was taken systematically from an MCMC chain of length 250 million.

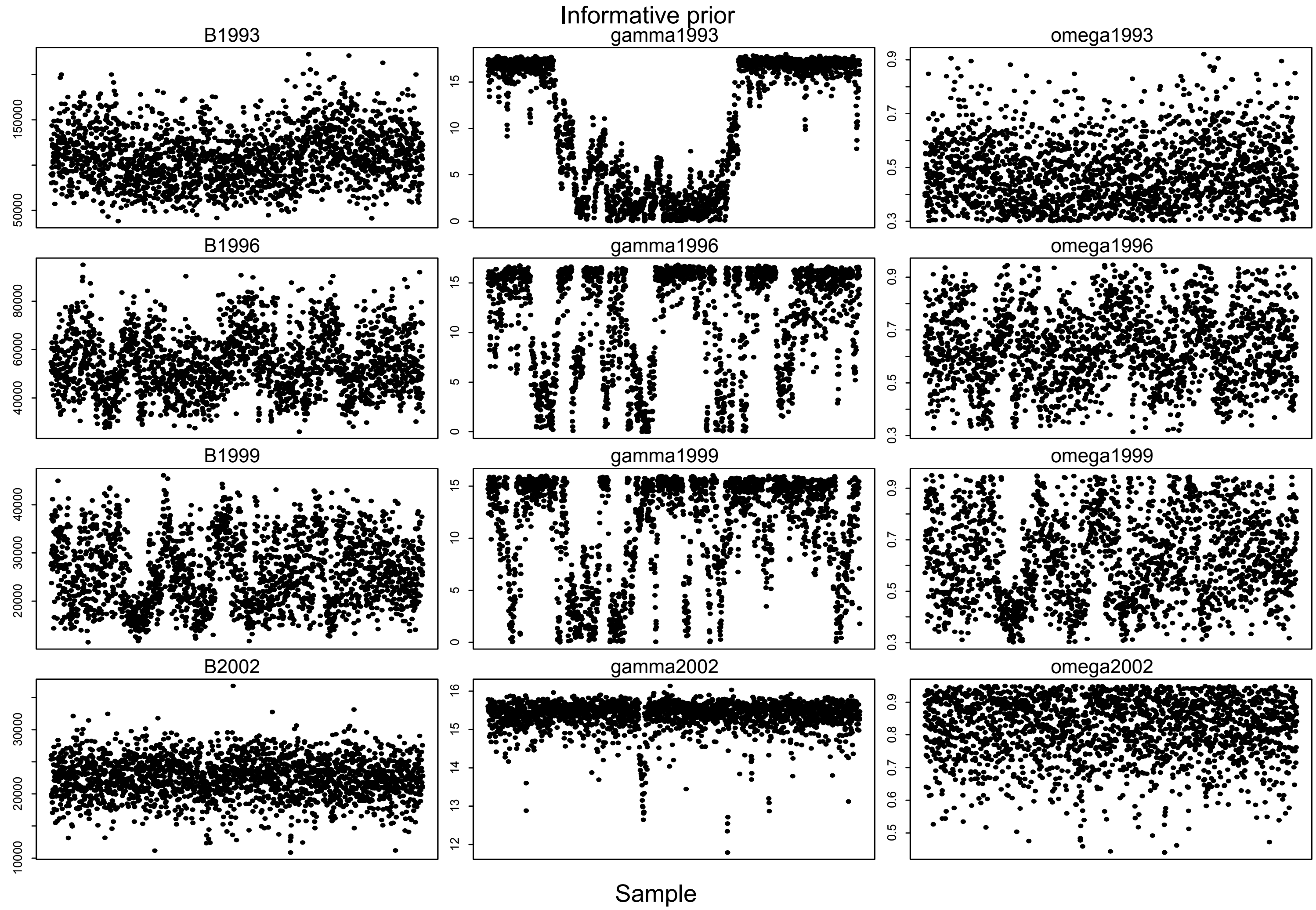


Figure H.6 Selected Case 2 MCMC chains for $B_{y,1}$, $\exp\left(\gamma_y\right)$, and ω_y. A sample of 2000 was taken systematically from an MCMC chain of length 100 million.

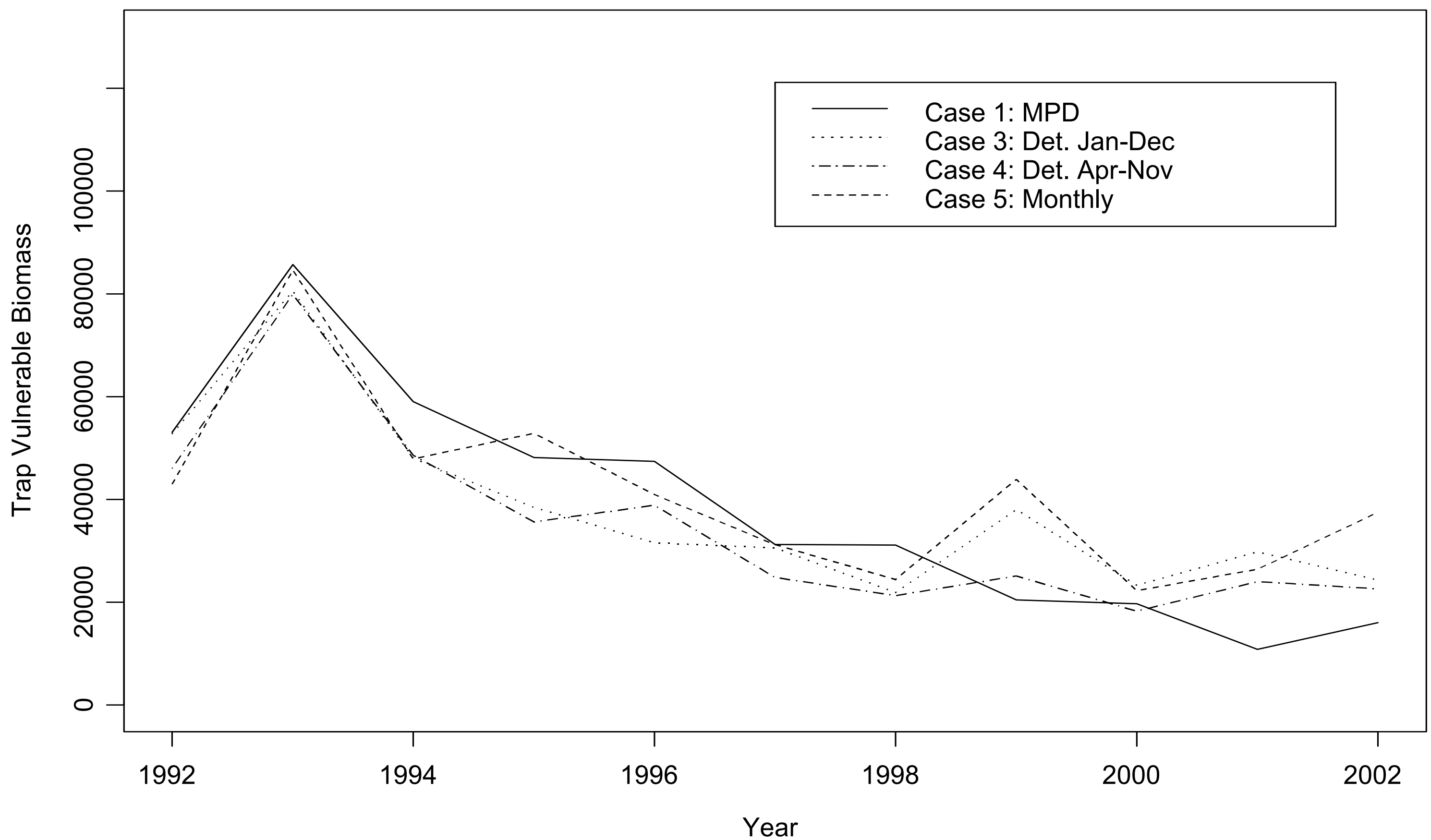


Figure H.7 Comparison of estimates of trap vulnerable biomass (t) for the deterministic, monthly, and new tagging models. See text for details of Cases.

APPENDIX I STANDARDIZED SURVEY DATA

I.1 SURVEY PROTOCOL I-1
Background *I-1*
Spatial distribution *I-1*
Depth distribution *I-2*
Vessels *I-2*
Gear *I-3*
Biological sampling *I-3*
I.2 CALCULATION OF SURVEY CATCH RATES I-4
I.3 SURVEY RESULTS I-4
2003 standardized survey results *I-4*
Annual survey catch rates *I-4*
Spatial effects *I-5*
Depth effects *I-6*
Temporal effects *I-7*
Effort *I-7*
Biological data *I-8*
I.4 SUMMARY I-8
I.5 LITERATURE CITED I-9

I.1 Survey Protocol

Background

Annual surveys beginning in 1990 shared a common protocol and were conducted at the same general time, locations and depths each year. Similar surveys were conducted in the fall of 1988 and 1989 (Table I.1), but these surveys used different trap baiting practices than those beginning in 1990 and are therefore not considered part of the standardized series. Catch rates observed during survey sets have been regarded as an index of trap vulnerable sablefish by Haist and Hilborn (2000), Haist et al. (2001), Kronlund et al. (2002), and Kronlund et al. (2003). Documentation of sablefish stock assessment surveys can be found in Smith et al. (1996) for 1988 to 1993, Downes et al. (1997) for 1994 and 1995, and Archipelago Marine Research (2000) for 2000. Surveys conducted from 1996 to 2000 were reported in aggregate by Wyeth and Kronlund (2003), and the 2001 survey was described by Wyeth et al. (2003). Results for the 2002 survey were documented by Kronlund et al. (2003). Tagging and biological studies conducted during 1982 to 1989 (Murie et al. 1995, Downes et al. 1997) are not considered comparable to the 1990 to 2003 surveys.

Spatial distribution

In 1988, eight indexing localities were purposively chosen for inclusion in an annual fishery-independent survey (Table I.2, Figure I.1 to Figure I.3). The survey was initiated to collect biological data and to establish standardized indexing sites. The eight localities were selected because they were fished by commercial vessels and were spatially dispersed about 60 nm apart such that normal weather conditions would permit all localities to be occupied within a 30 day period. A ninth locality (Cape St. James) was added in 1994. Sets conducted at sporadically distributed locations and times have not been included in the calculation of the abundance index series. Not all survey localities were visited in each year of the time series.

Depth distribution

The indexing survey was depth stratified in the sense that at each locality, sets were targeted within five depth ranges from 1990 to 2001 (three depth ranges in 1988 and 1989, Table I.3). In 1999, a sixth depth stratum was added to the Queen Charlotte Island localities between 600 and 800 fm. In 2000, three deep strata were added off the west coast of Vancouver Island: 650 to 700 fm, 750 to 800 fm, and 800 fm and deeper. A single 600 to 800 fm depth stratum was retained off the Queen Charlotte Islands due to the difficulty of setting gear accurately within 50 fm strata bounds in rugged bathymetric features. In 2002, depth strata at 650 to 750 fm and 750 to 999 fm were added to all survey localities. Deep strata at other sites not in the nine localities were discontinued (Table I.3). In 2003, the 750 to 999 fm depth stratum was discontinued at all localities except Barkley Canyon, where relatively high catch rates had been observed previously at these depths. In its place, a 50 to 150 fm stratum was added to all survey localities to investigate reports of high abundance of sablefish and the feasibility of using trap gear at shallow depths.

Spatial positions of the survey sets were not selected at random; rather the fishing master had discretion to set gear within each designated depth stratum at each survey locality. With rare exceptions, there was no replication of sets by depth and locality during the 1990 to 2003 period; usually a single set was conducted within each depth stratum for a given locality (Table I.4). However, in 2003 three replicate sets were conducted in each depth stratum at Hippa Island, Gowgaia Bay, and Esperanza Inlet to examine variability due to small scale spatial and temporal effects (Kronlund et al. 2003). The fishing master was instructed to spread the replicate sets out over time as much as possible, and was directed to avoid repeating the same set locations.

Due to the logistical difficulties of setting gear, a survey set may have been fished outside the intended depth stratum. Thus, some analyses use a mean observed depth to assign each set to a stratum rather than the intended target depth. The mean depth was determined by averaging the sounder depth recorded at one-minute intervals between anchors during deployment of the gear.

Vessels

Table I.1 also lists the vessel and skipper used in each survey year. The R/V W.E. Ricker carried out the surveys in 1991 to 1993 under the on-board direction of an experienced skipper from the sablefish commercial fleet. Surveys in other years have utilized a commercial charter vessel and experienced skipper. Standardized surveys conducted in 1996 to 1999, and 2001 used the same vessel and skipper. Similarly, the 2000 and 2002 standardized survey shared a common vessel and skipper. Onboard scientific technicians from Fisheries and Oceans Canada, or technicians provided through contractors, have varied over the 1990 to 2003 series.

Gear

Surveys were conducted using trap gear as described by Smith et al. (1996) and Wyeth et al. (2003). Trap design since 1988 has been a modified Korean trap consistent with that used by the commercial sablefish fleet. Beginning in 1990, a standardized string of 25 traps was deployed on each survey set. Traps were prepared prior to setting; bottoms were closed, tunnels stretched into place, and a bag of 1.0 to 1.5 kg of frozen squid fastened to the inside of the trap close to the tunnel entrance. Traps were attached to the ring and becket at 25 fm (46m) intervals along the groundline.

In 1988 and 1989 traps were baited with 1.0 to 1.5 kg of frozen squid in bait bags and four frozen hake (*Merluccius productus*) of 0.6 to 0.8 kg apiece. In 1988 approximately 100 traps were fished on each set so that the length of the string made it difficult to maintain traps within the designated depth stratum. In 1989, the number of traps on a string was reduced to approximately 70. Because of these differences, and pending analyses to standardize the 1988 and 1989 data to the 1990 through 2003 data, the 1988 and 1989 surveys were excluded from formal analyses. Kronlund et al. (2002) deemed this change in practice from previous stock assessments necessary because hake-baited traps are known to fish more successfully than traps baited with squid alone (Surry et al. pers. comm.). Table 4 in Haist et al. (2001) showed that catch rates (kg/trap) were substantially higher for the tagging sets baited with squid and hake than for survey index sets baited with squid alone. Furthermore, strings of gear with 70 or more traps might have different areas of sablefish attraction than strings of 25 traps, and the majority of traps set may not lie fully in a single depth stratum due to the length of the groundline.

Biological sampling

Sablefish caught on survey sets, as opposed to sets designated for tag application, were sampled for length, sex, and maturity. Otoliths were excised for subsequent age determination. Sablefish weight and girth were measured and stomachs were sampled for gut content analysis in some years. Tags may have been applied to sablefish caught by standardized survey sets when large catches were achieved.

I.2 Calculation of Survey Catch Rates

Each standardized set of survey gear consisted of a string of 25 traps. Catch was recorded in numbers of sablefish per trap and aggregate sablefish weight (kg) per trap. The aggregate weight may be an underestimate of the catch as fish may be partially eaten or reduced to frames by amphipod predation in some traps. The survey gear was inspected upon retrieval to determine if each trap was actually fishing ("effective") and not fouled or holed. The catch rate for each set was computed by summing the number (or weight) of sablefish in each effective trap, C_{tijk}, and dividing by the number of effective traps, n_{tijk}

(1) $$U_{tijk} = \frac{\sum_{l=1}^{n_{tijk}} C_{tijkl}}{n_{tijk}} \quad ,$$

where U_{tijk} is the catch rate for set *k* in depth stratum *j* of survey locality *i* for year *t*. The value U_{tijk} is the mean catch rate per trap for the set, but is hereafter referred to as the catch per unit effort (CPUE) for the set. Note that the number of effective traps may differ from 25 traps due to miscounting of traps on deployment, detection of fouled or holed gear upon retrieval, or lost traps.

I.3 Survey Results

2003 standardized survey results

Table I.6 is a summary of the catches and sampling for the 2003 sablefish standardized survey. There are no criteria applied to the selection of data in this table. Entries in the table show (1) the intended depth stratum rather than the depth stratum actually achieved, (2) the number of traps hauled rather than the traps fishing correctly, and (3) the nominal catch per trap by numbers and weight computed from the table entries. Note that the total number of sablefish recorded while hauling gear does not always equal the sum of sampled and recovered fish due to miscounting or fish lost overboard. In contrast to previous surveys, the standardized survey vessel did not conduct offshore tagging in 2002 or 2003 since tagging was carried out by a second charter vessel in both years.

Annual survey catch rates

Mean catch rates per trap are reported for each survey locality in numbers per trap (Table I.7) and in weight (kg) per trap (Table I.8) for the five core depth strata (D1-D5) used in calculating the survey abundance index. Exploratory analysis of time trends in the observed catch rate data was conducted separately for the north and south stock areas. Boxplots arrayed by year and stock area were used to summarize the distribution of CPUE values (mean number of fish per trap) achieved for each set (Figure I.4). The lower bound of the box indicates the first quartile (25^{th} percentile) of the data and the upper bound of the box is the third quartile (75^{th} percentile). The horizontal line that divides the box is the median (50^{th} percentile). The upper and lower whiskers of each boxplot are positioned at 1.5 times the inter-quartile range. Open circles indicate data values that fall outside the whiskers, or outliers. A filled circle represents the mean value of the data summarized in the boxplot. The lightly shaded rectangle positioned in each box represents an approximate 95 percent confidence interval for the sample median. A similar plot for survey catch rates in units of mean weight per trap is shown as Figure I.5.

The time trends of survey catch rates in both stock areas show a decline from high CPUE values in the early 1990s to a period of relative stability beginning in the mid-1990s. The 2001 survey produced the lowest mean and median catch rates observed in the times series, with marked reduction of the variance for the north stock area. Catch rates for the north stock area improved in 2002 relative to 2001, and were comparable to those observed in the mid-1990s but were more variable. The mean catch rate in 2003 increased substantially to a historical high for the north, with similarly high variability among sets. In contrast to the results in 2002, catch rates observed in 2003 for the south also increased substantially to a level similar to that observed in 1992.

Spatial effects

The nine localities surveyed over the course of the 1990 to 2003 time series are shown in Figure I.1 to Figure I.3, with 2003 set positions shown as red line segments and 1990 to 2002 set positions are shown as black line segments. Each line segments denotes the start and end position of a set. Commercial fishing sets are shown as light gray dots to illustrate the overlap of the survey localities with areas of commercial fishing. Locality bounds are shown as blue rectangles, and include the majority of survey sets from 1990 to 2003. The configuration of the bounding boxes has changed from that presented in Kronlund et al. (2002) to accommodate two deep depth strata added in 2002. However, the general localities surveyed remain similar to historical practice. Sets conducted in 2003 are not markedly different in spatial distribution from those completed during previous surveys, except at Cape St. James where two sets were positioned within the bounding rectangle but spatially removed from typical set positions.

Different catch rate characteristics were observed among the nine indexing localities. Multi-panel displays of CPUE by year for each locality are shown in Figure I.6. Data presented here correspond to depth strata 1 through 5 (Table I.3) which were fished in all survey years. Note that the catch rate scales differ among the panels to allow details of the time trends within each locality to be emphasized. Open circles represent the catch rate (mean number of fish per trap) achieved on each set. Filled circles are the arithmetic mean of the catch rates for each year. Two loess (Cleveland 1985) trend lines are superposed on each panel to illustrate the impact of the most recent survey; the solid line is the trend over the entire time series while the dashed line excludes the most recent survey point. The loess trend lines are fit using the observed catch rates rather than the annual means.

In general, time trends at all survey localities show a similar decline in catch rates from highs in the early 1990s. Beginning in the mid-1990s the rate of decline generally decreased or there was no trend through to 2002, depending on the locality. However, notable increases in trap CPUEs for 2002 were recorded for the north stock area at the Langara Island-North Frederick and Hippa Island survey localities while catch rates at the Buck Point and Gowgaia Bay localities were comparable to those observed in the mid 1990s. The 2003 survey returned the largest mean catch rate observed in the 14 year time series from northern B.C. Catch rates at Cape St. James, which have been highly variable over time with little direction in the trend, increased sharply in 2003. Similar improvements for southern survey localities also occurred in 2003, though the increase was more modest at Esperanza Inlet and less still at Barkley Canyon where one set showed improvement over 2002 results. Note, however, that the shallow (50 to 150 fm) D0 stratum, introduced for the 2003 survey, produced a catch rate among the highest observed in 2003 at the Barkley Canyon locality (Table I.6).

Depth effects

Protocols for standardized surveys prior to 2002 specified that the deepest depth stratum include depths greater than 1006 m (550 fm). In 2002, strata bounds at 1189 m (650 fm) and 1372 m (750 fm) were specified to ensure sampling of deep habitat (Table I.3). By design, the addition of the deep strata in 2002 resulted in sets distributed deeper than those achieved in the 1990 to 2001 period. Figure I.7 characterizes the catch rates (number of fish per trap) for each indexing set by mean bottom depth (m) for the localities in the north and south stock areas. Filled circles indicate catch rates observed in 2003. The catch rates for 1993, a year with similarly high catch rates, are shown as open crossed circles. Open circles represent catch rates for all other survey years from 1990 to 2002. Vertical dotted lines in each panel represent depth stratum boundaries for depth strata 0 through 7 (Table I.3). Three replicate sets conducted in each depth stratum at Hippa Inlet, Gowgaia Bay, and Esperanza Inlet in 2002 account for the greater number of observations by depth stratum at these localities.

In most cases the sets in 2003 achieved the target depth stratum or, if outside the target depth stratum, are very close to a boundary (see also Table I.4). Catch rates in depth strata 6 and 7 are among the lowest observed, reflecting either lower sablefish densities at these depths and/or decreased efficiency of trap gear at depth. Catch rates at the shallow depth stratum, D0, are generally very low, with the exception of one of the highest catch rate observed in the series at Barkley Canyon. In comparing 2003 and 1993 catch rates, note that 1993 catch rates were high within strata 1 through 5 whereas in 2003 high catch rates were limited to strata 1 through 3.

Catch (mean number of fish per trap) rates by year, depth and locality are shown in Figure I.8 for depth strata 1 through 5 which have been targeted in all survey years. With the exception of Barkley Canyon and depth stratum 1 at Hippa Island, catch rates for 2003 in depth strata 1 through 3 achieved values much greater than those observed in recent years. There were small increases in catch rates within depth stratum 4 at the Langara Island-North Frederick, Hippa Island, and Triangle Island localities. At other localities there was no evidence of improved catch rates in 2003 for depth strata 4 and 5. There are two general features of these data to note. First, the variation of observations around the trend line is relatively small. Second, there is interaction among years and depths, e.g., high catch rates at deep depths early in the time series for Barkley Canyon, but low catch rates in the latter half of the time series. Thus, the effect of depth over survey localities depends on which years are considered, but without replication of sets at each combination of locality, depth, and survey year, the interaction effects cannot be estimated. The implication is that depth dependent year effects, and hence abundance indices, exist.

Temporal effects

The timing of the survey sets from 1990 to 2001 has ranged from September 24 (1998) to November 20 (1990). Table I.1 lists the start and end dates of the survey by year and locality, where the start date is the day of the first survey index set and end date is the day of the last survey index haul. A research cruise or charter may have been longer in duration than indicated in Table I.1 to accommodate tagging sets and a component of the annual work conducted in mainland inlets. Figure I.9 shows the overlap in annual survey timing graphically, where each circle represents the start date of one survey set. The circles have been randomly perturbed, or jittered, along the y-axis of the plot to expose sets conducted on the same day. Survey timing shows a progressive enthusiasm for starting earlier in the fall until 1998. The timing of the 2003 survey was similar to that for the 2000 survey; sets were conducted somewhat later in October and early November due to starting on October 7 and weather days experienced in mid-October. The annual timing of the survey by locality is shown in Figure I.10, which shows that sets at Cape St. James, Triangle Island, and Quatsino Sound in 2003 occurred two to three weeks later than in recent years.

Effort

The standardized survey protocol from 1990 to 2003 specified that each set be completed using a string of 25 traps baited with squid and soaked for a period of 24 hours (Wyeth and Kronlund 2003, Wyeth et al. 2003). The duration of sets was usually within a few hours of the 24 hour soak time except where weather prevented retrieval of the gear (Figure I.11). Sets conducted during the early to mid 1990s sometimes greatly exceeded 24 hours, perhaps due to fishing operations being overtaken by inclement weather. The effect of soak time on catch rates (mean number per trap) is examined in Figure I.12. Soak times greater than about 30 hours appear to produce lower catch rates, however, there are many fewer observations with soak times between 40 and 60 hours than between 20 and 30 hours so this impression may be an artifact of sample size. Long soak times occurred at different localities among years (Figure I.13), so that their impacts may tend to average out among localities and years. Based on this graphical examination of effort effects, and due to the lack of replication in the survey, no adjustment for soak time was applied to the survey catch rates.

Biological data

Biological data collected for sablefish sampled during the standardized survey include fork length, sex, maturity, and otoliths for subsequent ageing. Ages are not available after 1996. Length frequency histograms by year and depth stratum for the north and south stock areas are shown in Figure I.14 and Figure I.15, respectively. Lengths are binned into 2 cm intervals. For the north stock area there is less mass in the length frequency distributions between 70 and 90 cm beginning in 2000 for depth strata 1 through 3. For the south stock area the length frequency distributions become less broad beginning about 1999; this feature is evident across depth strata, and particularly so when compared to fish measured in the early 1990s. The relative absence of fish in approximately the 70 to 90 cm range may be due to fishery removals, recruitment of smaller fish, or size-dependent immigration and emigration. In the absence of a population dynamics model the mechanism is difficult to identify and the possible lack of a discrete stock in B.C. means that attempts based solely on B.C. data may not be successful.

Individual fish weights are not generally available over the survey time. However, a ratio estimate of mean fish weight can be computed by dividing the total weight of sablefish caught on a set by the number of fish caught. These weights may be biased downwards for particular sets due, for example, to amphipod predation in the traps. The distribution of mean fish weights is summarized by boxplots in Figure I.16 by year for the coast, and north and south stock areas. There has been a decline in fish weight since 1995 over the coast, and fish weights are smaller by year in the south stock area than in the north stock area. Mean fish weight was lowest in 2001 for the north stock area, and in 1990 and 1991 for the south stock area.

The proportion of females by year and depth stratum is summarized in Figure I.17. The proportion of females was calculated for combinations of stock area, year and depth stratum. No attempt to weight the proportions by sample size was made. The proportion of females is largest over the time-series in depth strata 1 and 5, and decreases after 1996 in depth strata 2 and 3 for both stock areas. This raises the possibility that changes in length frequency noted above may be related to changes in sex ratios, since females are larger at age than males.

I.4 Summary

In general, catch rates observed in 2003 increased substantially over those observed in recent years, and are at historic highs for the north stock area. The trends over time at all survey localities show similar characteristics. Catch rates show typical correlation between mean and variance; higher catch rates imply higher observed variance. Survey results over time can be summarized as follows:

- a decline in catch rates from highs in the early 1990s for both north and south stock areas;
- beginning in the mid-1990s, the rate of decline generally decreased or there was a period of relative stability through to 2000, depending on the survey locality;
- the 2001 survey produced the lowest mean and median catch rates observed in the times series, with marked reduction of the variance for the north stock area in particular;
- catch rates for the north stock area improved in 2002 relative to 2001, and were comparable to those observed in the mid-1990s, but with higher variability;
- catch rates in 2003 increased substantially to a historical high, with similarly high variability among sets for the north stock area;
- catch rates in the south stock area exhibit a continuous decline from the mid-1990s to 2002, but show significant increases in 2003, similar to those observed in 1992;
- catch rates at the Barkley Canyon survey locality did not show general improvement over the low level observed in 2002.

The time trends suggest constant catch rates from the mid-1990s to 2002, with a very low point in 2001, for the north. For the south stock area, the time trend is a continuous decline from the mid-1990s to 2002. Both the north and south stock areas showed significantly greater catch rates in 2003 relative to 2002, with an associated increase in variance among sets.

I.5 Literature Cited

Archipelago Marine Research Ltd. 2000. A summary of the 2000 sablefish (*Anoplopoma fimbria*) survey conducted in British Columbia waters October 9 to November 13, 2000. Unpublished data report.

Cleveland, W.S. 1985. The elements of graphing data. Wadsworth, Monterey, California. xii+323 p.

Downes, A.J., Andrews, W.T., Smith, M.S., Saunders, M.W., and G.D. Jewsbury. 1997. Cruise details of sablefish (*Anoplopoma fimbria*) surveys conducted in B.C. waters, 1994-1995. Can. Data. Rep. Fish. Aquat. Sci. 1007: 106 p.

Haist, V. and R. Hilborn. 2000. Sablefish stock assessment for 2000 and recommended yield options for 2001. Can. Stock. Assess. Sec. Res. Doc. 2000/157. 78 p.

Haist, V., Hilborn, R., and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. Can. Sci. Advisory Res. Doc. 2001/135. 54 p.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

Kronlund, A.R., M. Wyeth, and R. Hilborn. 2002. Review of survey, commercial fishery, and tagging data for sablefish (*Anoplopoma fimbria*) in British Columbia: Supplement to the November 2001 sablefish stock assessment. Can. Sci. Adv. Sec. Res. Doc. 2002/074. 109 p.

Murie, D.J., Mitton, W., Saunders, M.W., and G.A. McFarlane. 1995. A summary of sablefish tagging and biological studies conducted during 1982-1987 by the Pacific Biological Station. Can. Data Rep. Fish. Aquat. Sci. 959: 84 p.

Smith, M.S., Saunders, M.W. and W.T. Andrews. 1996. Cruise details of sablefish (*Anoplopoma fimbria*) surveys conducted in B.C. waters 1988-1993. Can. Data Rep. Fish. Aquat. Sci. 976: 129 p.

Wyeth, M.R. and A.R. Kronlund. 2003. Sablefish (*Anoplopoma fimbria*) research and assessment surveys conducted in British Columbia waters from 1996 to 2000. Can. Data Rep. Fish. Aquat. Sci. 1116: 130 p.

Wyeth, M.R., A.R. Kronlund, and M. Elfert. 2003. Summary of the 2001 British Columbia sablefish (*Anoplopoma fimbria*) research and assessment survey. Can. Data Rep. Fish. Aquat. Sci. 1118. 54 p.

Table I.1 Indexing vessel timing, and skipper, for 1988 to 2003. Start Date is the date of the first indexing set and End Date is the date of the last indexing haul.

Year	Vessel	Skipper	Start Date	End Date	Trip ID
1988	F/V Vicious Fisher	Fletcher	October 31	November 23	43990
1989	F/V La Porsche	Brynjolfsen	October 21	November 17	43910
1990	F/V Viking Star	D. Farrington	November 08	November 18	43750
1991	R/V W.E. Ricker	A. Farrington	October 10	October 28	43673
1992	R/V W.E. Ricker	Roberts	October 15	November 03	43670
1993	R/V W.E. Ricker	A. Farrington	October 23	November 10	43650
1994	F/V La Porsche	Beauvais	October 15	October 25	43630
	F/V Western Viking	Jones	October 19	November 07	43390
1995	F/V Victor F	Derry	October 15	October 28	43330
	F/V Viking Sunrise	Olsen	October 10	October 25	43350
	F/V Ocean Pearl	Fraumeni/Gold	October 08	October 18	43270
1996	F/V Viking Star	Elvan	October 08	October 20	43210
	F/V Ocean Pearl	Derry	September 27	October 06	43039
1997	F/V Ocean Pearl	Derry	September 27	October 14	42699
1998	F/V Ocean Pearl	Derry	September 24	October 10	41122
1999	F/V Ocean Pearl	Derry	September 29	October 17	40589
2000	F/V Pacific Viking	Melynchuck	October 08	November 11	40517
2001	F/V Ocean Pearl	Derry	October 07	October 29	43233
2002	F/V Pacific Viking	Melynchuck	October 03	November 06	48120
2003	F/V Viking Star	J. Farrington	October 09	November 08	NA

Table I.2 Geographic boundaries of the standard survey localities.

Locality	Latitude North				Longitude West			
	Maximum		Minimum		Maximum		Minimum	
Langara Is.-North Frederick	54º	9’	53º	59’	134º	2’	133º	32’
Hippa Island	53º	32’	53º	20’	133º	24’	132º	55’
Buck Point	53º	14’	53º	1’	133º	10’	132º	35’
Gowgaia Bay	52º	27’	52º	17’	131º	51’	131º	33’
Cape St. James	51º	50’	51º	37’	130º	59’	130º	19’
Triangle Island	51º	8’	50º	58’	129º	55’	129º	31’
Quatsino Sound	50º	25’	50º	12’	128º	38’	128º	8’
Esperanza Inlet	49º	47’	49º	24’	127º	39’	127º	13’
Barkley Canyon	48º	24’	48º	10’	126º	12’	125º	53’

Table I.3 Depth strata boundaries by survey year.

Year	Stratum	Start depth fm (m)	End depth fm (m)
1988-1989	1	200 (366)	300 (549)
	2	300 (549)	400 (732)
	3	400 (732)	500 (915)
1990-2001	1	150 (275)	250 (457)
	2	250 (458)	350 (641)
	3	350 (642)	450 (824)
	4	450 (825)	550 (1006)
	5	550 (1007)	Deeper
2002	D1	150 (274)	249 (457)
	D2	250 (457)	349 (641)
	D3	350 (641)	449 (824)
	D4	450 (824)	549 (1006)
	D5	550 (1006)	649 (1189)
	D6	650 (1189)	749 (1372)
	D7	750 (1372)	999 (1827)
2003	D0	50 (91)	149 (274)
	D1	150 (274)	249 (457)
	D2	250 (457)	349 (641)
	D3	350 (641)	449 (824)
	D4	450 (824)	549 (1006)
	D5	550 (1006)	649 (1189)
	D6	650 (1189)	749 (1372)
	D7	750 (1372)	999 (1827)

Table I.4 Number of indexing sets at each survey locality by depth stratum and year. The number of intended sets is shown followed by the number of sets achieved, if different. The achieved depth stratum was calculated based on the mean of depth observations taken at one minute intervals.

Locality	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Barkley Canyon	D0														1
	D1			1	1	1	1	1	1	1	1	1, **2**	1	1	1
	D2	2	2	1	2	1	1	1	1	1	1	1, **0**	1	1	1
	D3	2	2	1	2	1	1	1	1	1	1	1	1	1	1
	D4	2	2	1	2	1, **2**	1	1	1	1	1, **2**	1	1	1	1
	D5	2, **1**	2	1	2	1, **0**	1	1	1	1	1, **0**	1	1	1	1
	D6													1	1
	D7													1	1
Esperanza Inlet	D0														1
	D1			1	1	1	1	1	1	1	1	1	1	3	1
	D2	2		1	1	1	1	1	1, **2**	1, **0**	1	1	1	3, **4**	1
	D3	2		1	1	1	1	1	1, **0**	1	1	1	1	3	1
	D4	2, **3**		1	1	1	1	1	1	1	1	1	1	3, **2**	1
	D5	2, **1**		1	1	1	1	1	1	1	1	1	1	3	1
	D6													3	1
	D7													3	
Quatsino Sound	D0														1
	D1	0, **1**		1	1	1	1	1	1	1	1	1	1	1	1
	D2	2, **1**	2	1	1	1	1	1	1	1	1	1	1	1	1
	D3	2	2	1	1	1, **2**	1	1	1	1	1	1	1	1	1
	D4	2	2	1	1	1	1	1	1	1	1	1	1	1	1
	D5	2	2	1	1	1, **0**	1	1	1	1	1	1	1	1	1
	D6													1	1
	D7													1	

Locality	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Triangle Island	D0														1
	D1			1		1	1	1	1, **2**	1	1	1, **2**	1	1	1
	D2		1	1	1	1	1	1	1, **0**	1	1	1, **0**	1	1	1
	D3		1	1	1	1	1	1	1	1	1	1	1	1	1
	D4		1	1	1	1	1	1	1	1	1	1	1	1	1, **2**
	D5		1	1	1	1	1	1	1	1	1	1	1	1, **2**	1, **0**
	D6													1, **0**	1
	D7													1	
Cape St. James	D0														1
	D1					1	1	1	1, **2**	1	1	1	1	1	1
	D2					1	1	1	1, **0**	1	1	1	1	1	1
	D3					1	1, **0**	1	1	1	1	1	1	1	1
	D4					1	1	1	1	1, **0**	1	1	1	1	1
	D5					1, **0**	1	1	1	1, **2**	1	1	1	1	1
	D6													1, **2**	1
	D7													1, **0**	
Gowgaia Bay	D0														1
	D1					1	1	1	1	1	1	1	1	3	1
	D2		1	1	1	1, **0**	1	1	1	1	1	1	1	3	1
	D3		1	1	2	1	1	1	1	1	1, **2**	1	1	3	1
	D4		1	1	1	1	1	1	1	1	1, **0**	1	1, **0**	3	1
	D5		1	1	1	1, **0**	1	1	1	1	1	1	1	3, **4**	1, **2**
	D6													3, **5**	1, **0**
	D7													3, **0**	

Locality	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Buck Point	D0														1
	D1			1	1	1	1	1	1	1	1	1	1	1	1
	D2		1	1	1	1	1	1, **2**	1	1	1	1	1	1	1
	D3		1	1	1	1	1	1	1	1, **0**	1	1	1	1	1
	D4		1	1	1	1	1	1, **0**	1	1	1	1	1	1	1
	D5		1	1	1	1	1	1	1	1	1	1	1	1	1
	D6													1, **2**	1
	D7													1, **0**	
Hippa Island	D0														1, **0**
	D1				1	1	1	1		1	1	1	1	3	1
	D2			1	1	1	1	1		1	1	1	1	3	1, **2**
	D3			1	1	1	1	1		1	1, **2**	1	1	3	1
	D4			1	1, **2**	1	1	1		1	1, **0**	1	1	3, **2**	1
	D5			1	1, **0**	1, **0**	1	1		1	1	1	1	3, **5**	1
	D6													3, **4**	1
	D7													3, **1**	
Langara Island-	D0														1
North Frederick	D1			1		1	1	1	1, **2**	1	1	1	1	1	1
	D2		1	1	1	1	1	1	1, **0**	1	1	1, **2**	1	1	1
	D3		1	1	1	1	1, **2**	1, **2**	1	1	1	1	1	1	1
	D4		1	1	1	1	1, **0**	1, **0**	1	1	1	1, **0**	1	1	1
	D5		1	1	1	1, **0**	1	1	1	1	1	1	1	1	1
	D6													1	1
	D7													1	

Table I.5 List of index sets excluded from survey data analysis.

Year	Location	Set	Depth Stratum	Reason for exclusion
1990	Barkley Canyon	23	5	only 3 traps hauled, remainder of the string lost
1994	Cape St. James	3	5	bridge log indicates extra 25 set for vessel, but not in data report, baiting unclear
1994	Gowgaia Bay	6	5	extra 50 traps for vessel, catch not recorded, baiting unclear
1994	Gowgaia Bay	11	2	extra 35 traps for vessel baited with hake and squid bait
1994	Hippa Island	18	5	extra traps for vessel, catch not recorded, baiting unclear
1994	Langara Island-North Frederick	24	5	extra 33 traps for vessel baited with hake and squid bait
1995	Cape St. James	11	3	trap set every second becket
1998	Esperanza Inlet	13	1	unsure count of traps
1998	Buck Point	57	3	tangled with another string
2001	Gowgaia Bay	66	4	set across another vessel's string

Table I.6 2003 indexing survey data for south and north stock areas.

Locality	Intended Depth Stratum	Set Number	Traps Hauled	Sablefish					Nominal CPUE	
				LSMO Sampled	LS Sampled	Recovered	Total	Weight (kg)	Fish/ Trap	kg/ Trap
Barkley Canyon	D0	1	25	47	771	0	827	2261.59	33.08	90.46
	D1	2	25	61	26	0	89	242.34	3.56	9.69
	D2	3	23	63	185	0	249	621.72	10.83	27.03
	D3	4	25	53	20	0	73	138.7	2.92	5.55
	D4	5	25	56	0	0	55	121.52	2.20	4.86
	D5	6	20	59	24	0	86	174.38	4.30	8.72
	D6	8	25	26	0	0	28	90.9	1.12	3.64
	D7	7	26	8	0	0	8	30.88	0.31	1.19
Esperanza Inlet	D0	9	25	91	215	0	301	914.66	12.04	36.59
	D1	11	25	68	408	2	479	1345.66	19.16	53.83
	D2	10	25	48	194	1	244	648.92	9.76	25.96
	D3	12	26	48	79	3	130	342.48	5.00	13.17
	D4	13	25	45	0	0	45	110.5	1.80	4.42
	D5	14	25	51	69	0	122	279.54	4.88	11.18
	D6	15	25	40	0	1	41	125.78	1.64	5.03
Quatsino Sound	D0	83	25	19	0	0	19	64.5	0.76	2.58
	D1	84	25	61	88	0	946	2542.2	37.84	101.69
	D2	80	25	51	103	0	328	877.9	13.12	35.12
	D3	81	24	49	128	1	356	912.8	14.83	38.03
	D4	82	25	58	39	0	96	266	3.84	10.64
	D5	78	25	28	0	0	28	101.9	1.12	4.08
	D6	79	25	42	0	0	42	121.4	1.68	4.86
Triangle Island	D0	77	25	46	110	0	167	491.7	6.68	19.67
	D1	76	25	49	134	1	292	699.8	11.68	27.99
	D2	75	24	55	110	0	319	867.2	13.29	36.13

Locality	Intended Depth Stratum	Set Number	Traps Hauled	Sablefish LSMO Sampled	LS Sampled	Recovered	Total	Weight (kg)	Nominal CPUE Fish/ Trap	kg/ Trap
	D3	74	25	62	135	3	660	1234.7	26.40	49.39
	D4	73	25	58	119	0	234	479.6	9.36	19.18
	D5	71	24	45	0	0	45	116.6	1.88	4.86
	D6	72	26	14	0	0	14	48.7	0.54	1.87
Cape St. James	D0	64	25	9	0	0	9	41.8	0.36	1.67
	D1	65	25	64	148	2	507	1433.6	20.28	57.34
	D2	66	25	47	136	0	367	1015.7	14.68	40.63
	D3	67	24	55	115	3	215	594.1	8.96	24.75
	D4	68	25	32	0	0	32	88.1	1.28	3.52
	D5	69	24	18	0	0	18	64.3	0.75	2.68
	D6	70	26	6	0	0	6	23.5	0.23	0.90
Gowgaia Bay	D0	60	25	16	0	0	15	42.4	0.60	1.70
	D1	61	25	47	146	1	560	1794.96	22.40	71.80
	D2	62	23	42	73	1	444	1221.7	19.30	53.12
	D3	63	25	44	119	3	179	476.2	7.16	19.05
	D4	59	25	48	0	0	48	176.6	1.92	7.06
	D5	58	25	17	0	0	17	66.3	0.68	2.65
	D6	57	24	13	0	0	13	50	0.54	2.08
Buck Point	D0	56	23	4	0	0	4	10.6	0.17	0.46
	D1	55	24	46	133	1	467	1455.2	19.46	60.63
	D2	54	25	48	120	2	539	1580.3	21.56	63.21
	D3	53	25	49	144	2	366	996.4	14.64	39.86
	D4	52	25	29	0	0	29	86.6	1.16	3.46
	D5	51	24	13	0	0	13	41.9	0.54	1.75
	D6	50	25	15	0	0	15	47	0.60	1.88
Hippa Island	D0	44	25	36	0	0	36	127.84	1.44	5.11
	D1	43	24	50	114	3	419	1343.7	17.46	55.99

Locality	Intended Depth Stratum	Set Number	Traps Hauled	Sablefish LSMO Sampled	LS Sampled	Recovered	Total	Weight (kg)	Nominal CPUE Fish/ Trap	kg/ Trap
	D2	45	26	56	136	3	456	1391.4	17.54	53.52
	D3	46	20	53	105	1	457	1168.32	22.85	58.42
	D4	47	25	66	21	5	92	254	3.68	10.16
	D5	48	25	54	0	0	54	101.2	2.16	4.05
	D6	49	25	22	0	0	22	71.9	0.88	2.88
Langara Island-North Frederick	D0	36	23	5	0	0	5	22.54	0.22	0.98
	D1	37	25	64	78	0	215	667.8	8.60	26.71
	D2	38	24	51	128	0	455	1378.44	18.96	57.44
	D3	39	25	65	143	1	419	1262.44	16.76	50.50
	D4	40	25	48	47	0	96	341.85	3.84	13.67
	D5	41	25	14	0	0	14	45.38	0.56	1.82
	D6	42	25	5	0	0	5	24.08	0.20	0.96
Total			**1,577**	**2,652**	**4,863**	**40**	**12,931**	**35,782.72**	**8.20**	**22.69**

Table I.7 Sample mean catch rate (number fish per trap) of survey index sets by core depth stratum, locality, stock, and year. Sets assigned to depth strata based on the mean of depth observations taken at one minute intervals. Fouled or holed traps excluded from summary. Summary means are applied to the set by set observations.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Barkley Canyon	1			13.76	23.04		7.92	3.12	7.52	1.46	2.15	2.78	0.16	1.83	3.60
	2	15.74	6.73	24.65	26.32	22.42	8.92	3.72	6.92	2.16	1.56		0.64	2.52	10.83
	3	7.38	9.50	18.92	16.78	7.84	6.40	6.08	6.88	2.36	1.87	13.28	2.64	5.84	2.92
	4	14.85	23.60	21.04	19.44	18.54	10.40	8.24	5.44	7.21	6.53	12.48	8.13	5.88	2.20
	5	11.72	15.82	19.16	12.56		7.92	9.68	6.64	8.76		11.04	5.28	4.00	4.18
	Mean	12.52	13.91	19.51	19.25	16.83	8.31	6.17	6.68	4.39	3.73	8.47	3.37	4.02	4.74
Esperanza Inlet	1			7.48	13.63	9.40	4.84	5.32	10.12	4.04	4.13	6.48	1.68	1.04	19.16
	2	8.16		12.40	16.76	8.64	8.17	2.40	4.28		2.67	5.00	0.29	1.11	9.76
	3	5.14		8.24	12.16	6.36	4.72	1.72		1.63	2.32	2.42	0.81	3.47	5.20
	4	10.33		10.60	20.48	3.52	13.45	2.72	1.58	1.52	2.04	7.33	0.96	5.44	1.80
	5	9.60		16.36	21.88	8.44	5.25	6.64	5.70	7.42	5.61	3.00	4.81	7.02	5.08
	Mean	8.4		11.02	16.98	7.27	7.29	3.76	5.19	3.65	3.35	4.85	1.71	3.33	8.2
Quatsino Sound	1	3.68		5.38	6.88	3.96	3.30	2.52	2.33	2.75	3.50	3.08	1.57	0.84	37.84
	2	5.70	2.66	8.36	11.63	6.96	3.76	2.56	1.04	4.20	3.28	4.08	0.88	3.00	13.12
	3	3.30	2.76	7.08	10.24	3.20	2.16	1.88	0.21	5.68	3.32	3.84	5.76	1.96	14.83
	4	5.40	9.50	14.64	4.08	1.72	3.32	1.76	0.24	2.36	3.60	8.05	5.88	0.58	3.84
	5	6.90	5.94	9.32	5.32		4.30	2.52	0.52	2.12	4.88	2.24	1.64	1.60	1.13
	Mean	5.07	5.21	8.96	7.63	3.81	3.37	2.25	0.87	3.42	3.72	4.26	3.15	1.6	14.15
Triangle Island	1			5.44		3.52	4.48	5.08	2.30	1.64	2.68	4.36	0.96	0.28	11.68
	2		4.67	11.12	11.56	9.44	7.52	4.72		3.84	3.16		0.78	1.68	13.29
	3		1.33	10.36	9.20	4.42	7.76	2.84	3.56	2.36	2.67	5.12	0.48	2.88	26.40
	4		1.71	4.64	7.25	0.36	4.00	1.60	0.44	4.88	1.36	1.12	0.56	0.52	5.58
	5		1.13	4.32	6.76	0.36	4.28	2.40	1.37	6.28	1.14	1.21	0.44	0.90	
	Mean		2.21	7.18	8.69	3.62	5.61	3.33	1.99	3.8	2.2	3.23	0.65	1.19	12.51
Southern Stock	**Mean**	8.5	8.09	11.66	14.39	7.41	6.14	3.88	3.68	3.82	3.25	5.2	2.22	2.75	9.9
Coast	**Mean**	8.5	7.46	8.88	11.61	5.49	4.26	3.39	2.7	3.64	2.58	3.47	1.27	2.96	9.96

Table I.7 Continued.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Cape St. James	1					1.62	3.17	2.44	1.56	2.13	4.22	2.04	1.08	0.24	20.28
	2					3.32	2.08	3.52		3.80	5.74	4.95	2.72	2.56	14.68
	3					4.20		4.43	3.24	1.96	3.36	3.08	0.64	6.00	8.60
	4					3.91	0.88	1.80	1.52		1.71	1.74	0.17	0.84	1.28
	5						1.38	1.64	0.56	1.15	0.38	0.35	0.11	0.32	0.72
	Mean					3.26	1.88	2.77	1.69	2.04	3.08	2.43	0.95	1.99	9.11
Gowgaia Bay	1					1.81	3.48	3.67	3.48	3.00	0.68	0.58	0.36	2.93	22.40
	2		11.75	11.63	14.83		7.24	2.56	4.00	4.84	2.09	6.13	0.42	3.28	19.30
	3		4.33	8.71	13.81	9.25	6.40	2.76	1.36	4.72	1.03	2.61	0.69	2.03	7.16
	4		2.63	3.56	7.12	3.76	5.40	2.00	0.64	3.29		2.08		1.39	1.92
	5		3.96	4.76	6.84		1.68	1.68	0.60	3.92	0.28	1.32	0.35	1.01	0.61
	Mean		5.67	7.16	11.28	4.94	4.84	2.53	2.02	3.95	1.02	2.54	0.45	2.06	8.67
Buck Point	1			3.12	9.32	2.00	2.40	2.62	0.64	3.85	2.09	2.96	0.44	3.67	19.46
	2		7.21	11.71	12.50	6.80	2.72	4.80	3.92	4.80	2.32	4.60	0.67	5.16	21.56
	3		2.13	10.32	5.00	4.09	3.92	1.60	0.96		2.04	1.20	0.24	2.84	15.13
	4		3.79	7.35	4.16	4.36	1.50		0.48	1.72	0.80	1.72	0.16	0.68	1.16
	5		2.29	4.92	3.36	3.12	1.40	3.54	0.60	4.52	0.31	1.24	0.40	0.72	0.54
	Mean		3.85	7.48	6.87	4.07	2.39	3.47	1.32	3.72	1.51	2.34	0.38	2.61	11.57
Hippa Island	1				1.14	2.96	1.80	2.27		1.96	0.88	1.56	0.56	4.53	1.44
	2			4.79	10.84	2.40	2.16	4.21		4.92	1.48	2.44	0.72	5.69	17.50
	3			3.76	8.76	2.88	4.40	6.38		6.60	0.84	1.96	0.08	5.52	22.85
	4			7.36	6.62	5.52	2.00	4.00		3.92		1.40	0.43	2.00	3.68
	5			4.44			2.24	5.13		0.58	2.64	0.52	0.28	2.26	2.16
	Mean			5.09	6.8	3.44	2.52	4.4		3.6	1.34	1.58	0.41	3.91	10.85
Langara Island-North Frederick	1			1.72		1.74	0.28	1.88	2.48	3.40	0.24	2.67	0.08	3.80	8.60
	2		10.29	4.16	10.43	3.96	2.71	2.52		6.29	6.44	1.50	0.36	16.16	19.65
	3		8.33	1.24	9.28	2.32	2.34	0.98	1.24	2.96	4.20	1.33	0.11	5.12	16.76
	4		9.13	4.20	6.04	3.16			1.12	4.76	3.08		0.16	1.56	3.84
	5		11.16	6.60	5.92		0.68	2.72	2.08	3.52	2.48	0.44	0.40	0.84	0.56
	Mean		9.73	3.58	7.92	2.79	1.67	1.82	1.88	4.19	3.29	1.49	0.22	5.5	9.88
Northern Stock	**Mean**		6.42	5.8	8.23	3.66	2.69	3	1.73	3.49	2.05	2.08	0.48	3.11	10
Coast	**Mean**	8.5	7.46	8.88	11.61	5.49	4.26	3.39	2.7	3.64	2.58	3.47	1.27	2.96	9.96

Table I.8 Sample mean catch rate (kg/trap) of survey index sets by core depth stratum, locality, stock and year. Sets assigned to depth strata based on the mean of depth observations taken at one minute intervals. Fouled or holed traps excluded from summary. Summary means are applied to the set by set observations.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Barkley Canyon	**1**			33.44	54.84		28.44	12.08	23.90	5.21	7.55	8.30	0.38	5.03	9.72
	2	39.86	12.65	74.00	65.82	58.54	26.33	13.04	20.76	5.84	4.91		1.53	5.50	27.03
	3	18.98	16.34	39.67	49.46	24.76	21.64	16.20	14.65	6.68	4.26	25.68	5.70	11.90	5.55
	4	30.24	41.54	41.80	46.64	37.70	26.76	21.28	13.13	14.63	15.14	25.60	17.97	11.12	4.86
	5	25.40	33.40	39.96	32.58		18.32	23.28	15.71	17.12		27.48	13.71	8.79	8.44
	Mean	29.08	25.98	45.77	49.32	39.68	24.3	17.18	17.63	9.89	9.4	19.07	7.86	8.47	11.12
Esperanza Inlet	**1**			25.48	51.63	24.84	15.08	19.04	28.92	13.00	14.02	20.92	5.84	3.46	53.83
	2	21.80		36.56	39.12	15.52	26.71	7.80	6.29		7.21	15.42	0.89	3.23	25.96
	3	13.12		24.16	40.60	15.68	13.60	4.52		4.67	5.90	5.21	1.60	6.61	13.70
	4	21.13		27.24	54.88	9.56	28.65	7.36	2.90	3.33	4.79	15.46	2.19	9.98	4.42
	5	18.28		38.12	59.40	21.60	14.55	14.00	10.84	16.23	14.29	7.80	11.50	16.04	11.65
	Mean	18.94		30.31	49.13	17.44	19.72	10.54	11.05	9.31	9.24	12.96	4.4	7.42	21.91
Quatsino Sound	**1**	12.56		20.29	26.96	17.72	11.04	8.04	6.72	10.75	14.41	8.50	4.59	2.72	101.69
	2	12.00	5.92	27.52	34.93	19.20	12.04	8.60	2.72	13.36	9.62	10.00	2.20	7.69	35.12
	3	9.72	7.02	20.48	33.36	9.14	5.64	5.00	0.49	14.80	9.05	9.32	11.96	4.00	38.03
	4	15.94	18.79	35.32	16.08	3.96	8.68	5.88	0.41	8.00	12.58	15.41	10.57	1.26	10.64
	5	14.72	14.92	22.96	19.96		15.70	8.72	0.86	6.28	14.43	5.96	3.29	3.99	4.16
	Mean	13.16	11.66	25.31	26.26	11.83	10.62	7.25	2.24	10.64	12.02	9.84	6.52	3.93	37.93
Triangle Island	**1**			23.96		9.36	14.48	17.28	8.31	5.48	8.76	13.30	3.34	0.81	27.99
	2		13.79	33.16	36.04	22.60	24.61	14.92		11.32	8.26		2.06	4.46	36.13
	3		3.63	26.56	25.20	12.25	26.72	9.24	10.73	7.76	7.88	11.52	1.11	6.58	49.39
	4		6.96	18.04	33.29	0.76	15.96	7.52	1.25	16.56	4.08	4.12	1.78	1.76	11.92
	5		5.42	15.20	29.40	1.40	17.28	9.36	5.66	26.00	5.26	4.79	1.53	3.17	
	Mean		7.45	23.38	30.98	9.27	19.81	11.66	6.85	13.42	6.85	9.41	1.97	3.32	27.47
Southern Stock	**Mean**	20.02	16.55	31.2	41.07	18.5	18.61	11.66	9.44	10.9	9.38	12.82	5.19	6.23	24.61
Coast	**Mean**	20.02	19.34	25.57	36.51	15.57	13.66	11.26	7.72	12.04	7.72	9.3	3.09	8.22	27.35

Table I.8 Continued.

Location	Stratum	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Cape St. James	**1**					6.88	11.42	8.11	5.40	7.22	13.67	6.54	3.14	0.74	57.34
	2					9.56	7.42	13.20		13.20	17.34	14.27	6.51	6.65	40.63
	3					13.20		14.57	8.86	5.58	9.32	8.79	1.49	14.32	23.76
	4					16.23	3.08	6.56	4.74		5.22	6.30	0.49	2.16	3.52
	5						6.54	8.32	2.37	4.73	1.53	1.22	0.42	1.52	2.57
	Mean					11.47	7.11	10.15	5.36	7.09	9.42	7.43	2.41	5.08	25.57
Gowgaia Bay	**1**					7.67	14.08	15.00	12.13	10.76	2.43	2.08	0.94	10.50	71.80
	2		47.04	41.96	61.25		24.88	8.72	12.22	18.20	5.30	17.63	1.35	9.83	53.12
	3		15.54	20.25	52.17	35.71	21.20	10.04	3.94	17.08	3.46	8.04	2.20	5.69	19.05
	4		11.58	11.52	29.56	17.44	19.96	7.52	2.30	13.25		6.36		3.62	7.06
	5		17.25	18.24	31.64		6.96	6.60	2.78	16.75	1.20	4.52	0.97	3.41	2.37
	Mean		22.85	22.99	45.36	20.27	17.42	9.58	6.67	15.21	3.17	7.73	1.36	6.41	25.96
Buck Point	**1**			12.65	44.12	7.20	9.16	9.19	2.08	14.35	6.63	10.04	1.31	12.23	60.63
	2		26.75	40.42	33.00	20.28	9.20	13.84	11.05	16.12	5.86	13.24	1.74	13.51	63.21
	3		5.58	27.36	14.40	11.65	11.68	4.44	2.49		4.12	2.96	0.56	7.75	41.19
	4		11.33	24.30	15.56	15.80	4.29		1.55	6.20	2.50	5.00	0.49	1.74	3.46
	5		7.67	16.00	12.84	11.80	4.68	11.04	1.91	14.04	1.20	3.96	1.17	2.30	1.75
	Mean		12.83	24.15	23.98	13.35	7.8	10.47	3.82	12.68	4.06	7.04	1.06	7.51	34.05
Hippa Island	**1**				3.95	9.52	6.80	7.82		7.33	2.64	4.72	2.06	15.00	5.11
	2			18.46	30.68	9.68	6.76	18.25		17.50	4.12	9.68	1.65	18.31	54.75
	3			11.64	30.68	9.52	13.52	26.13		22.52	1.73	5.56	0.16	16.15	58.42
	4			24.64	24.54	13.40	6.77	15.72		15.80		5.08	1.49	5.81	10.16
	5			14.48			7.56	18.75		2.63	11.13	2.00	0.83	5.72	4.05
	Mean			17.3	22.88	10.53	8.28	17.33		13.16	4.27	5.41	1.24	11.79	31.21
Langara Island-North Frederick	**1**			6.68		7.91	0.84	7.67	12.99	17.16	0.78	9.75	0.44	15.29	26.71
	2		37.79	14.84	45.61	14.48	12.33	11.84		26.21	23.65	4.42	1.09	53.57	59.55
	3		30.00	4.64	32.16	7.96	8.64	3.74	4.48	11.88	13.29	3.58	0.17	16.14	50.50
	4		34.35	14.72	22.72	9.96			3.47	15.56	8.74		0.51	5.24	13.67
	5		42.92	24.92	27.12		2.60	8.80	6.83	11.80	8.82	1.76	1.12	3.25	1.82
	Mean		36.26	13.16	31.9	10.08	6.61	7.16	8.15	16.52	11.06	4.79	0.67	18.7	30.45
Northern Stock	**Mean**		23.98	19.32	30.98	12.79	9.54	10.94	6	12.94	6.39	6.48	1.35	9.52	29.38
Coast	**Mean**	20.02	19.34	25.57	36.51	15.57	13.66	11.26	7.72	12.04	7.72	9.3	3.09	8.22	27.35

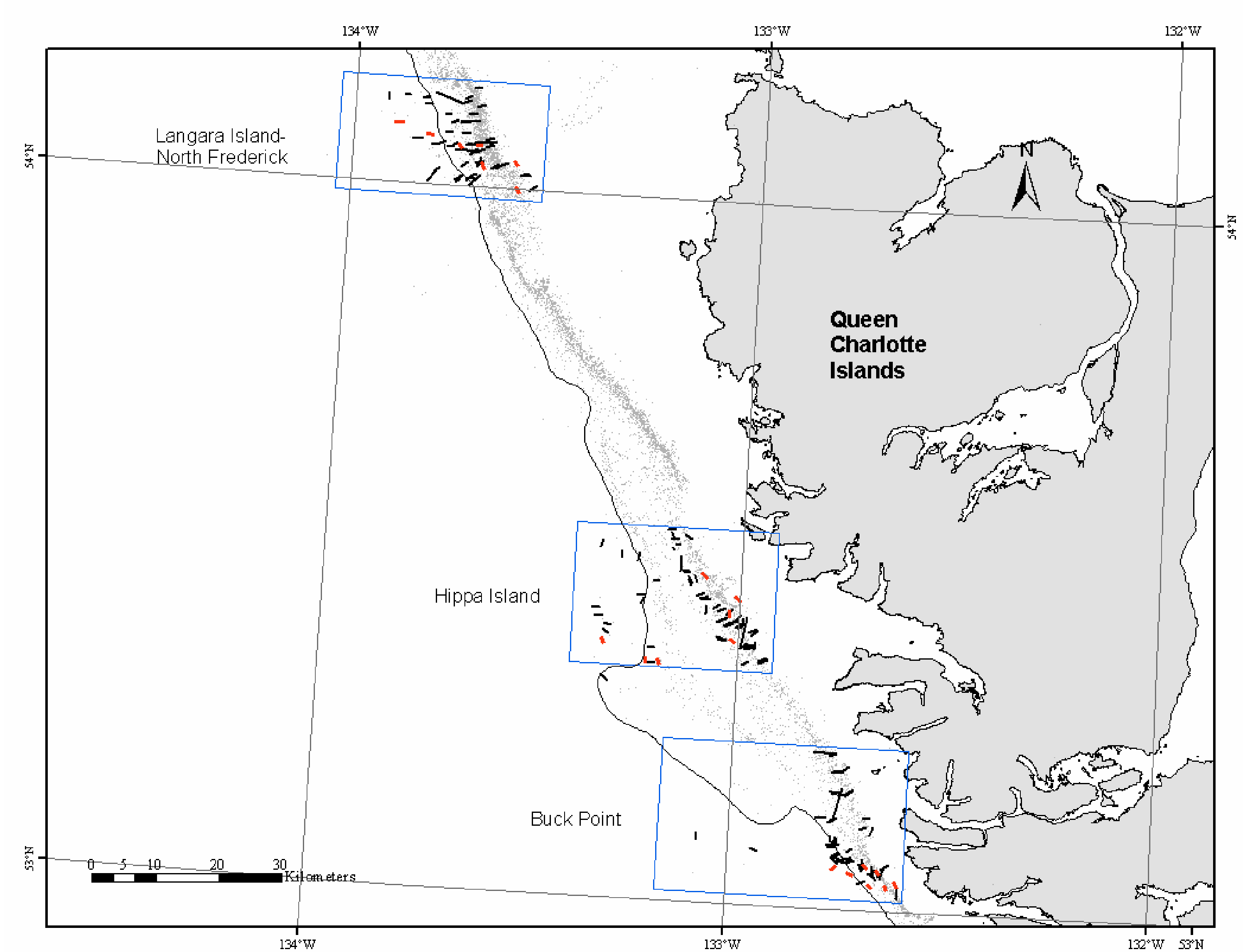


Figure I.1 Standardized survey localities at Langara-Frederick Island, Hippa Island, and Buck Point. The rectangles indicate the locality boundaries. Standardized sets from 1990 to 2002 are indicated by thick black lines while the 2003 sets are indicated by thick red lines. Small grey circles indicate the start positions of commercial sets. The 1000 m depth contour is shown as a curved solid line.

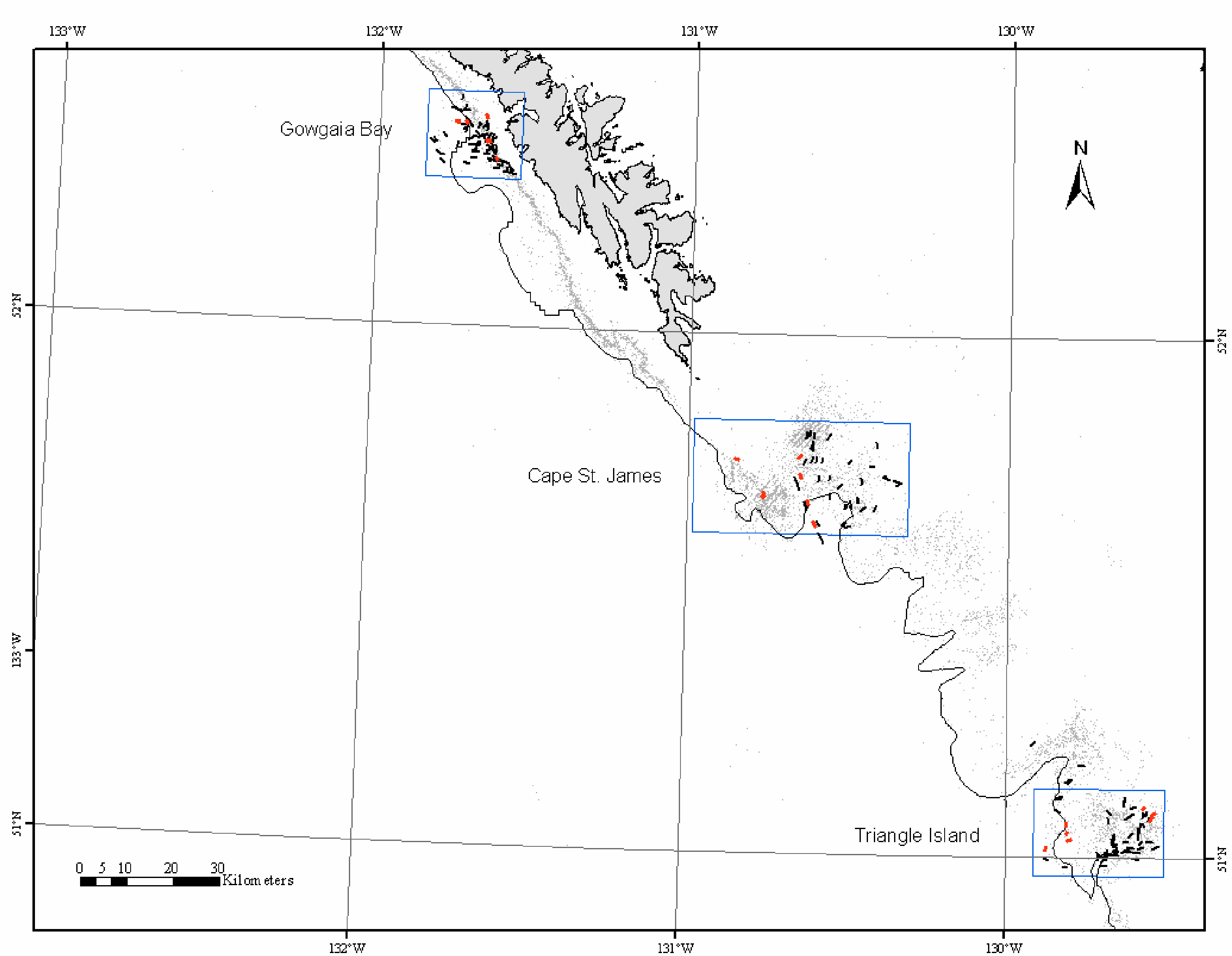


Figure I.2 Standardized survey localities at Gowgaia Bay, Cape St. James, and Triangle Island. The rectangles indicate the locality boundaries. Standardized sets from 1990 to 2002 are indicated by thick black lines while the 2003 sets are indicated by thick red lines. Small grey circles indicate the start positions of commercial sets. The 1000 m depth contour is shown as a curved solid line.

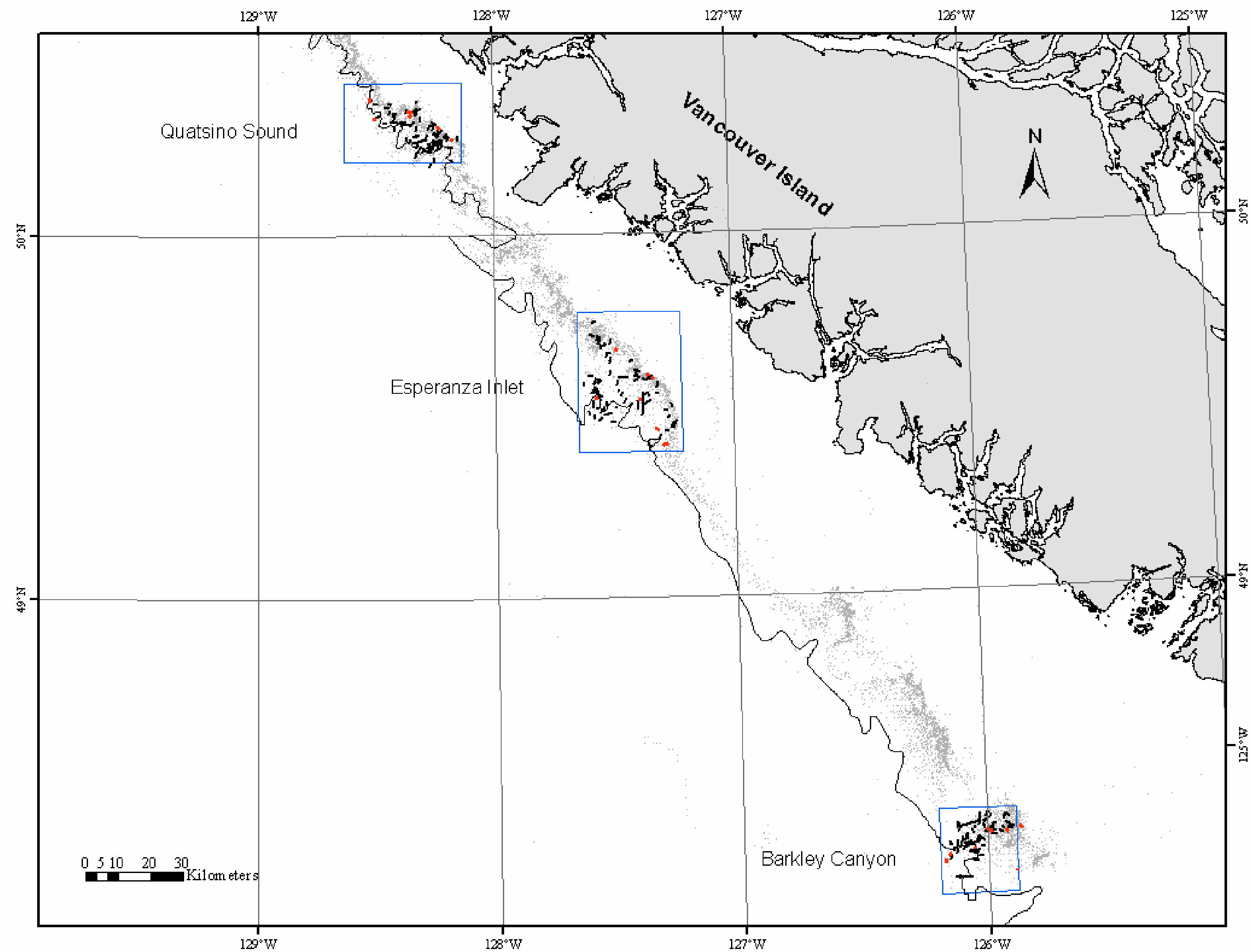


Figure I.3 Standardized survey localities at Quatsino Sound, Esperanza Inlet, and Barkley Canyon. The rectangles indicate the locality boundaries. Standardized sets from 1990 to 2002 are indicated by thick black lines while the 2003 sets are indicated by thick red lines. Small grey circles indicate the start positions of commercial sets. The 1000 m depth contour is shown as a curved solid line.

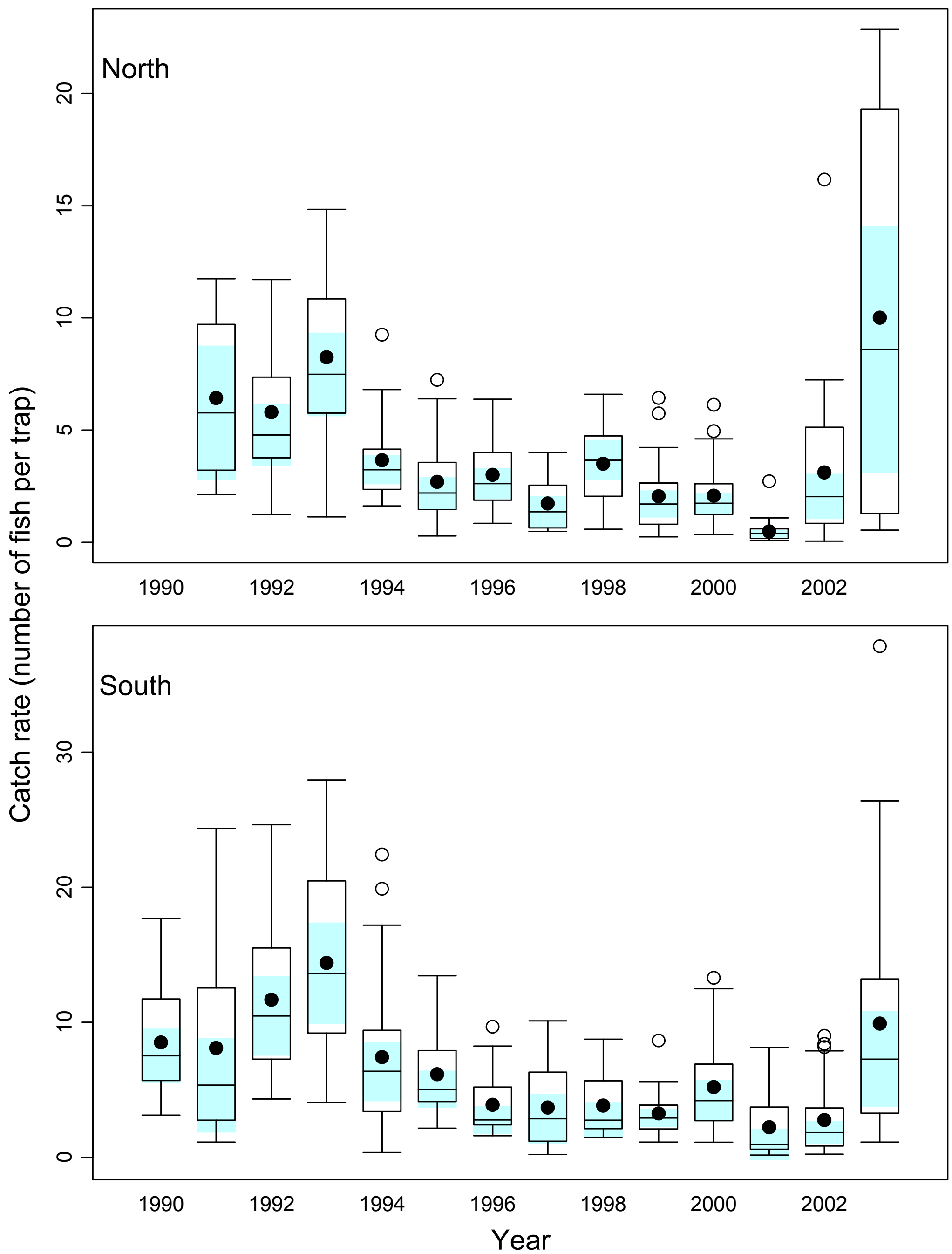


Figure I.4 Distribution of catch rates (numbers per trap) for standardized sets in depth strata 1 through 5, summarized by boxplots for each year and stock area. The filled circles show the annual mean catch rate. The shaded rectangle for each year indicates an approximate 95 percent confidence interval on the median annual catch rate.

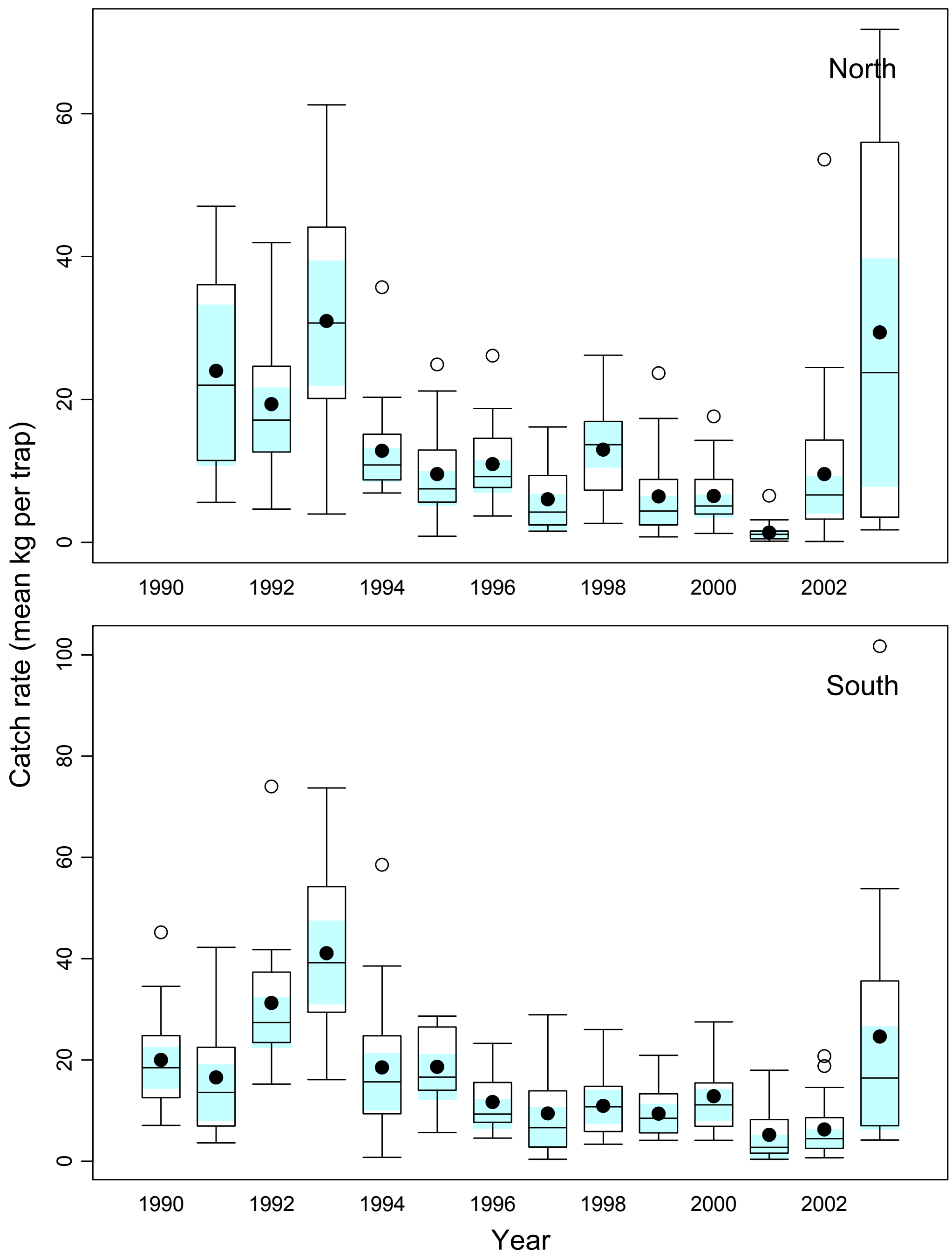


Figure I.5 Distribution of catch rates (kg per trap) for standardized sets in depth strata 1 through 5, summarized by boxplots for each year and stock area. The filled circles show the annual mean catch rate. The shaded rectangle for each year indicates an approximate 95 percent confidence interval for on the median annual catch rate.

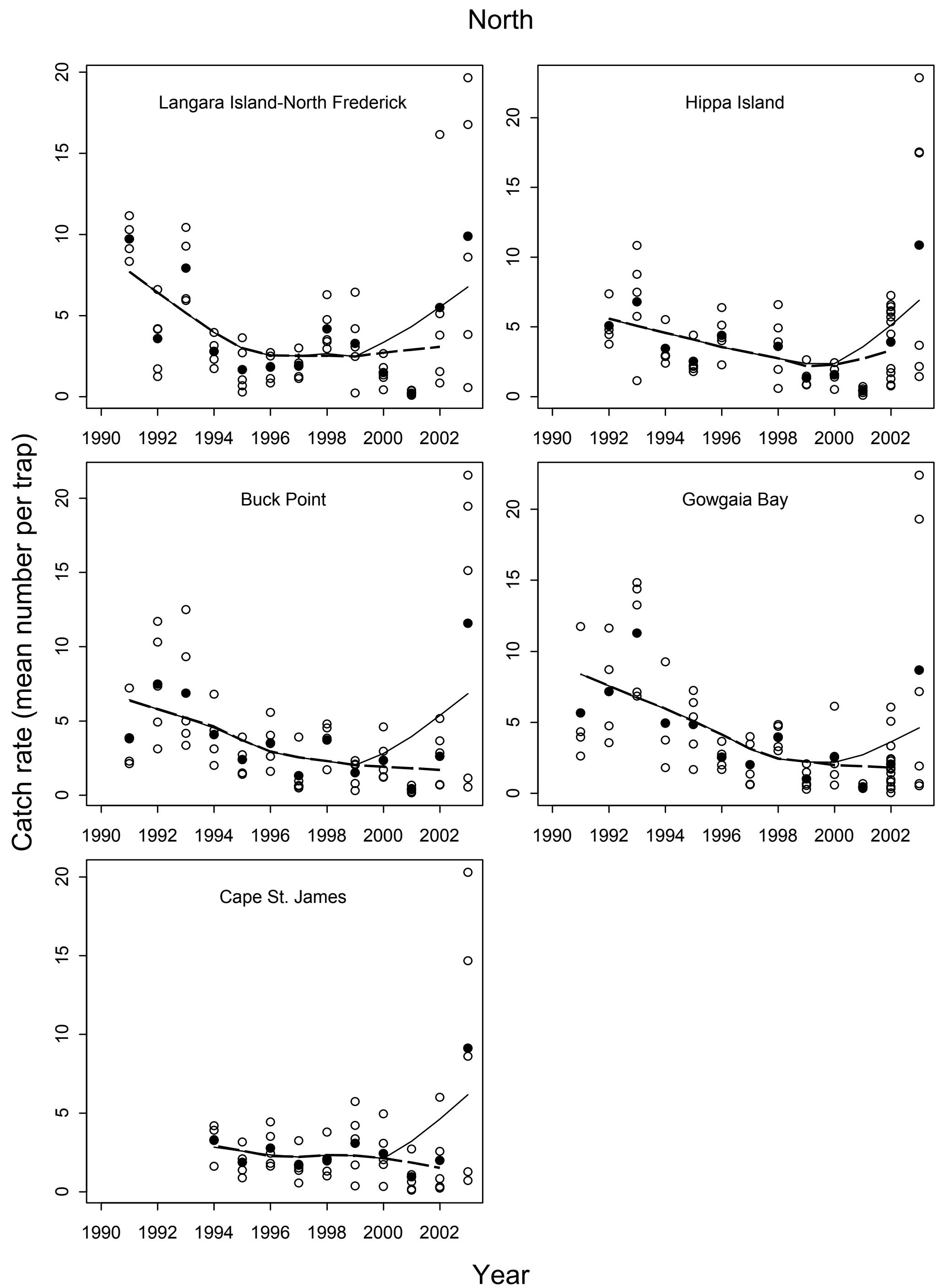


Figure I.6 Catch rates (numbers per trap) for standardized sets by year and locality. Open circles represent the catch rate for each set. Filled circles indicate the annual mean of the catch rate observations. The solid curve shows a loess trend line fit to the entire time series, while the dashed line excludes data for 2003.

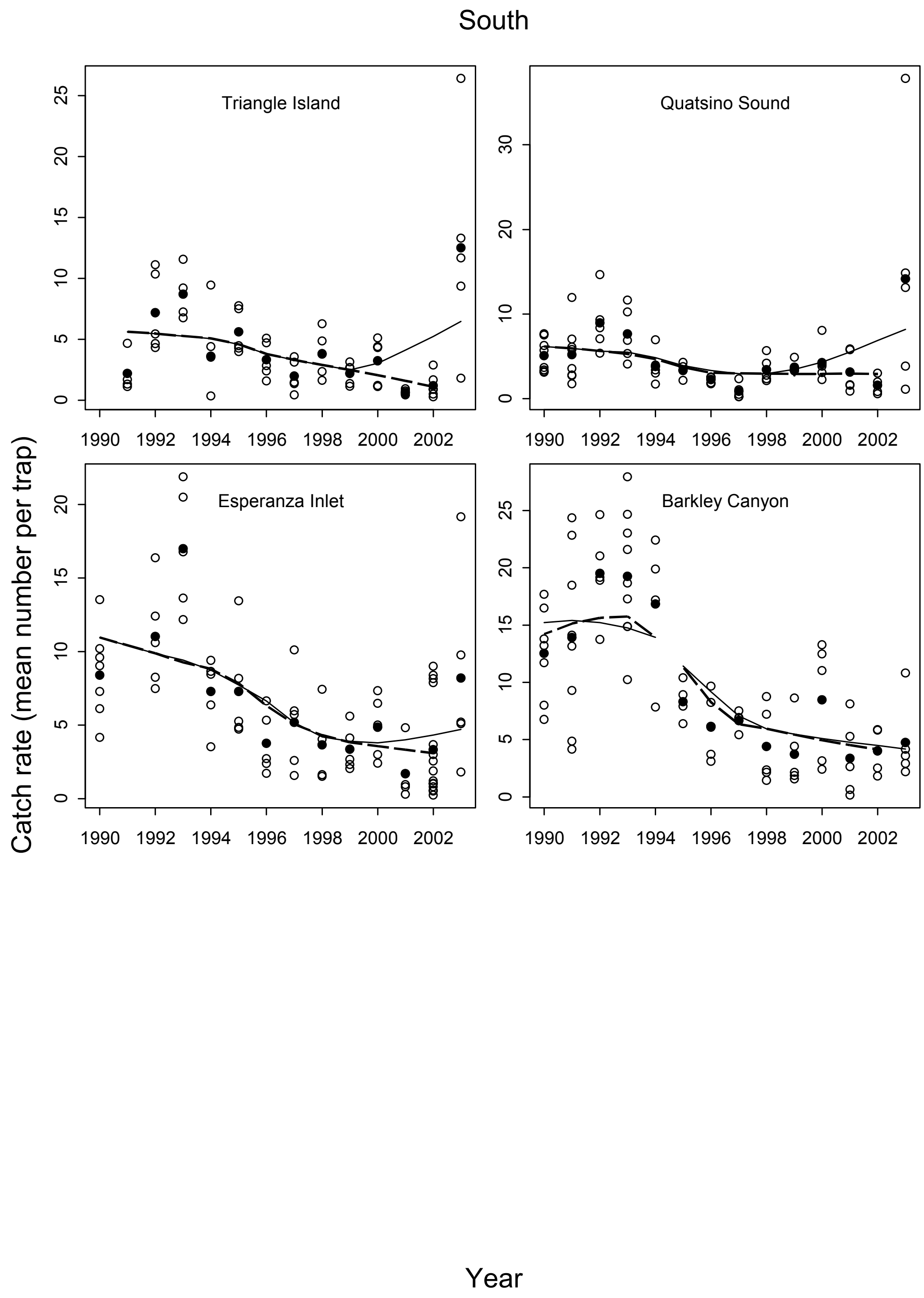


Figure I.6 Continued.

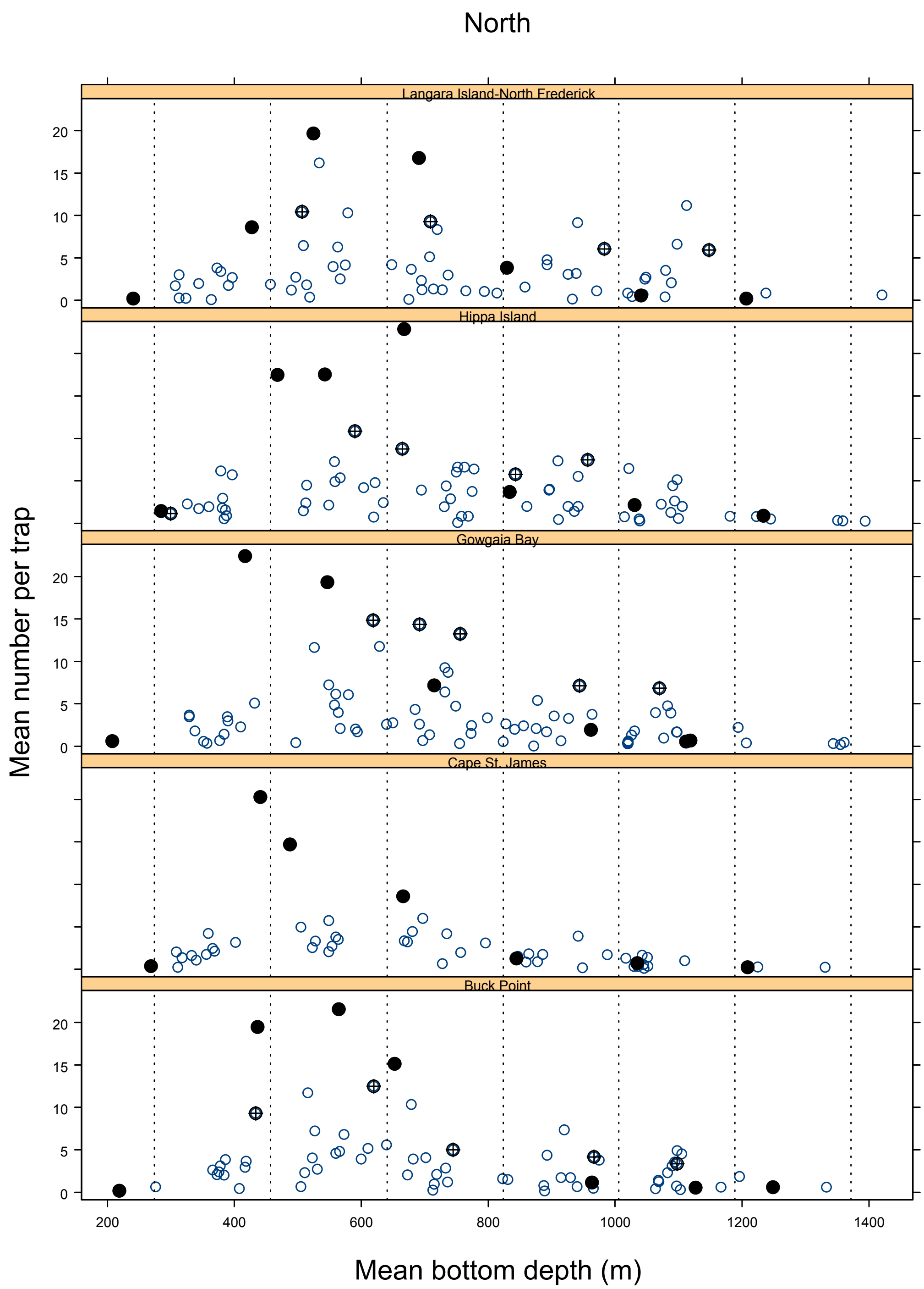


Figure I.7 Catch rates (mean number per trap) for the northern localities plotted against mean bottom depth. Sets conducted in 2003 and 1993 are shown as solid circles and open crossed circles.

South

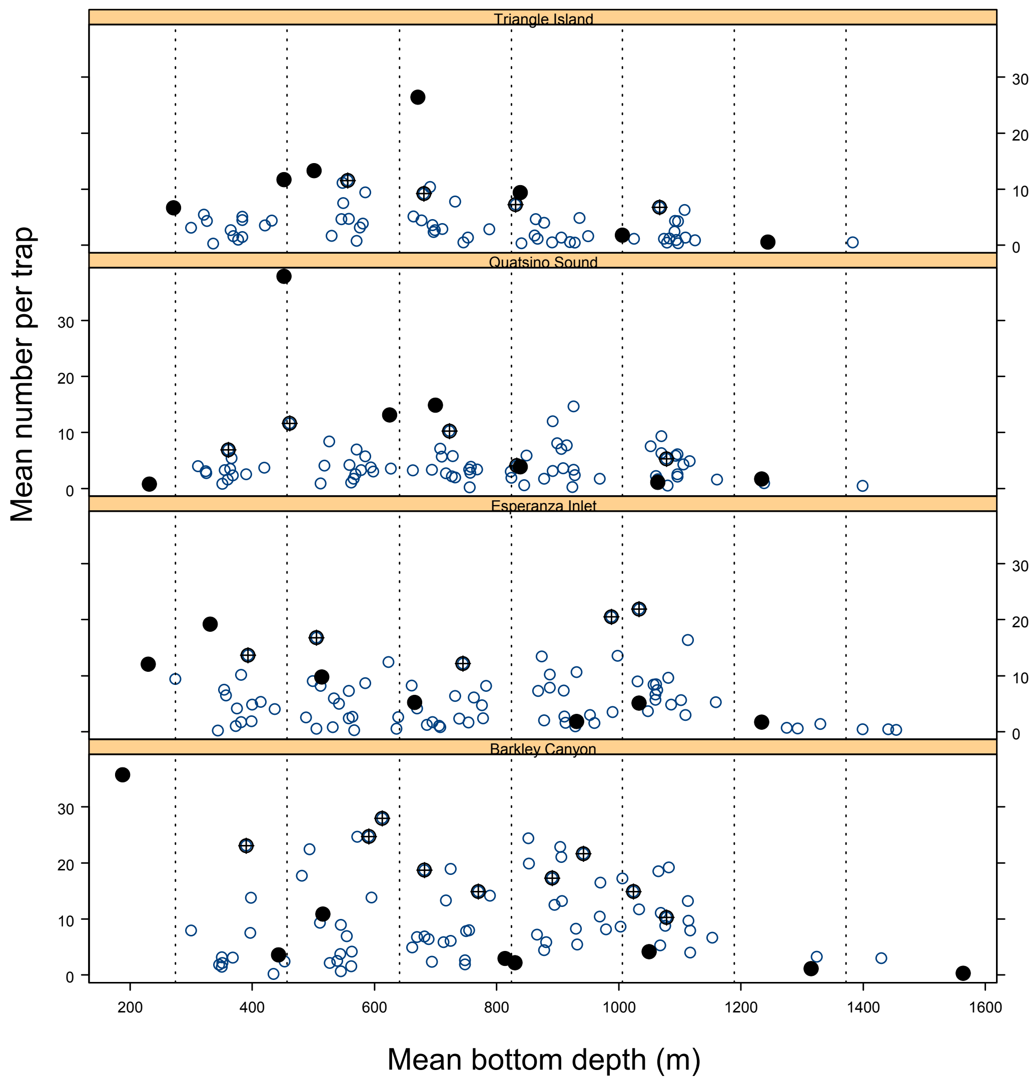


Figure I.7 Continued.

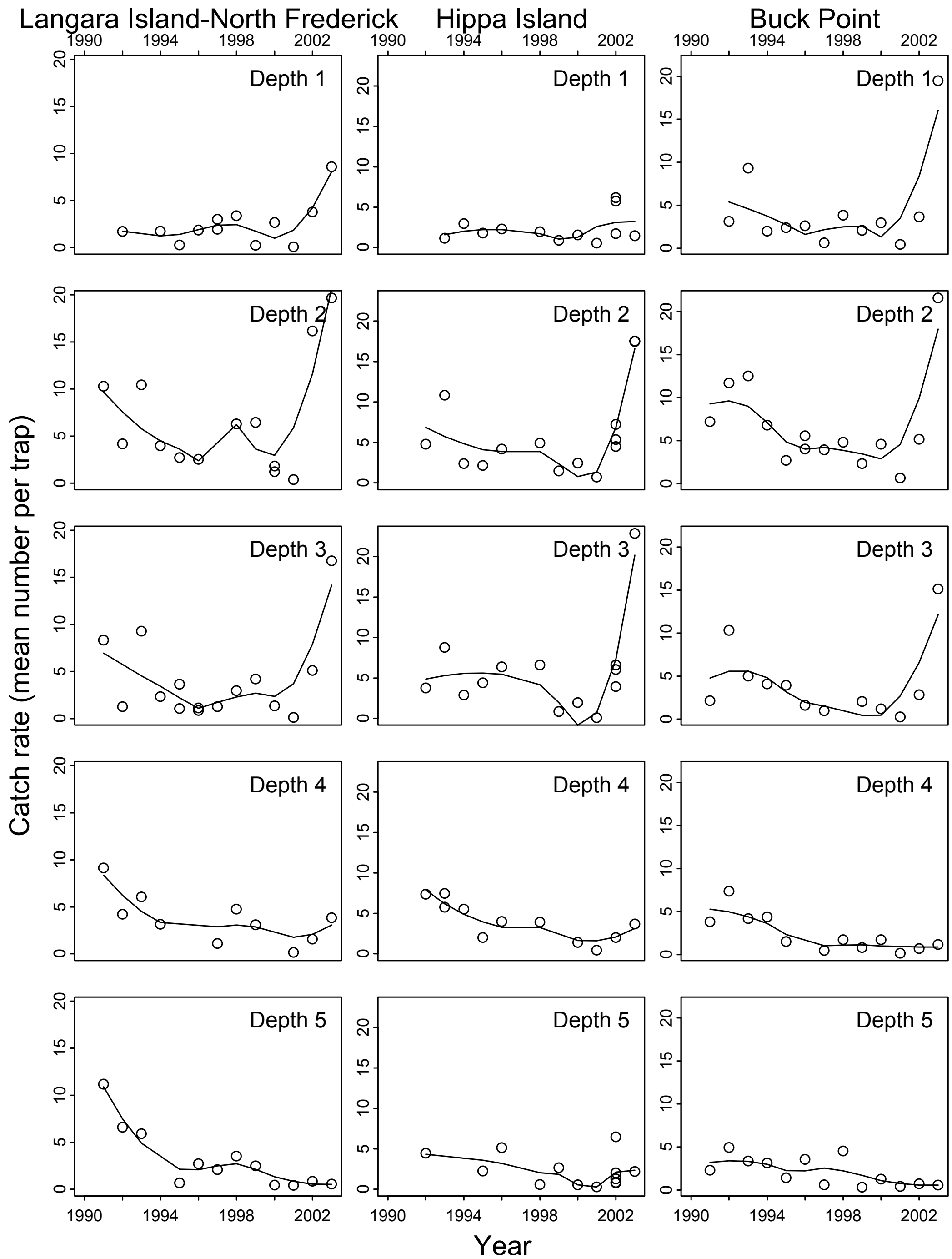


Figure I.8 Survey catch rates (mean number of fish per trap) by year, depth strata 1 through 5, and locality. The solid curve is a loess smooth through the observations.

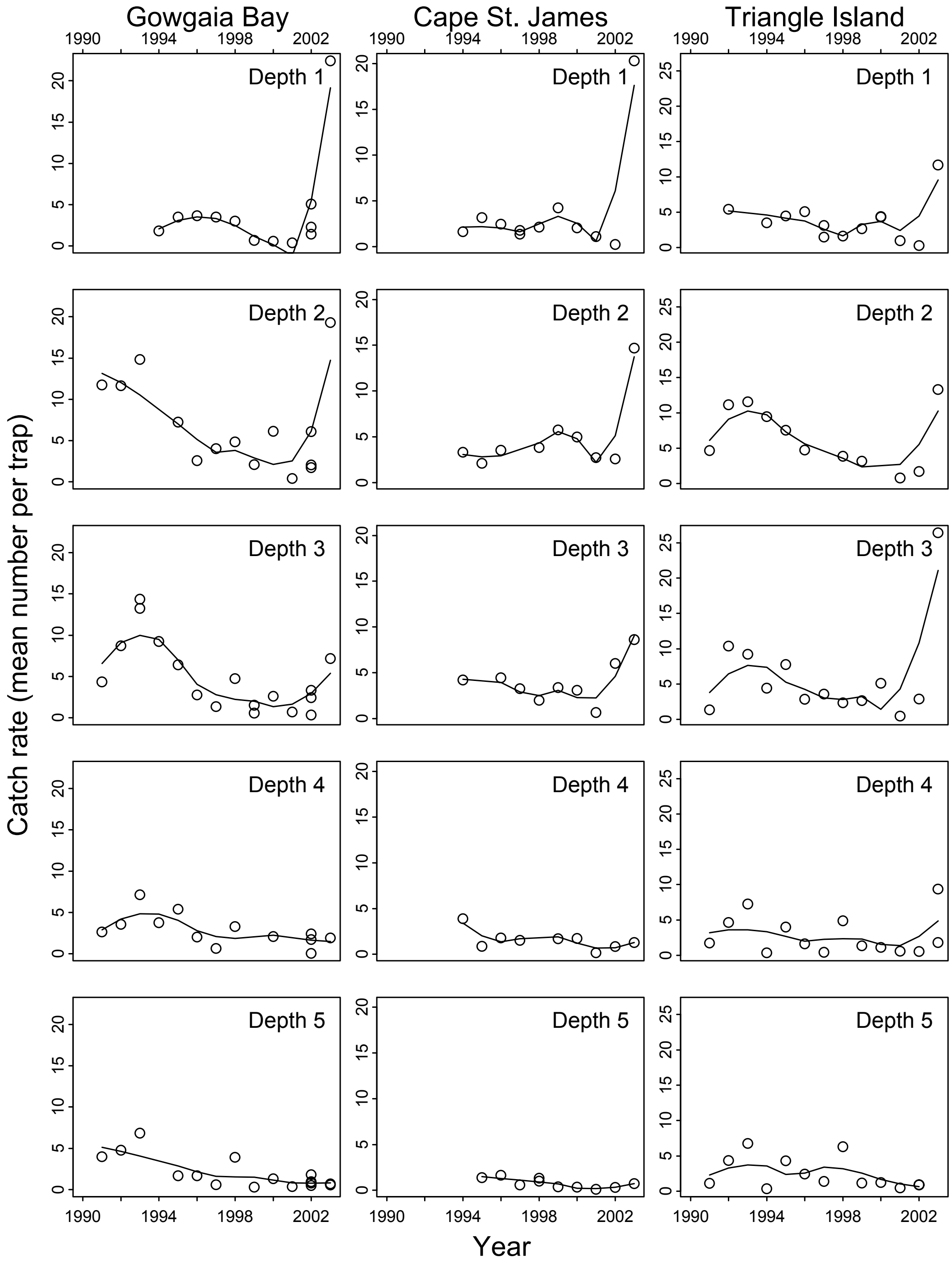


Figure I.8 Continued.

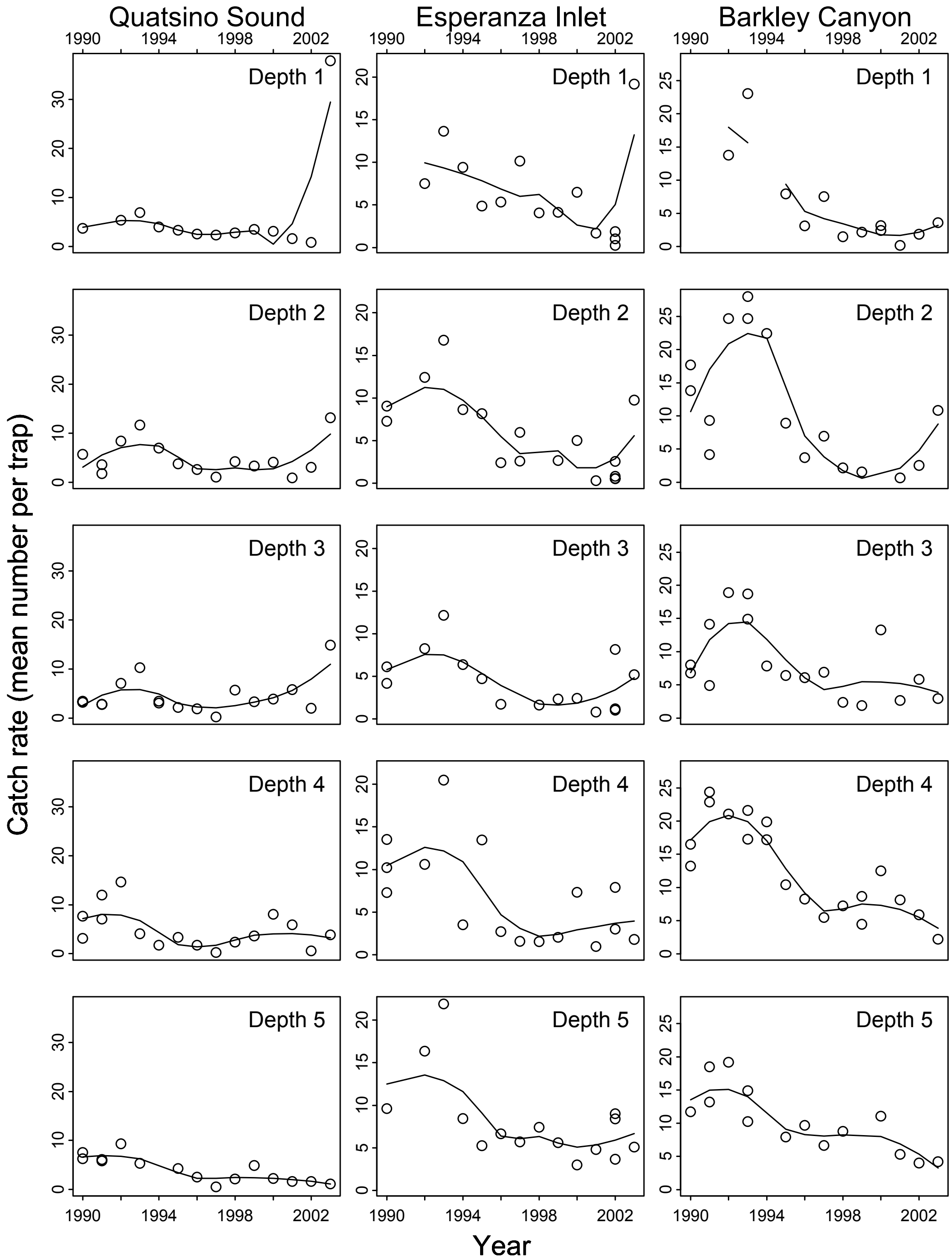


Figure I.8 Continued.

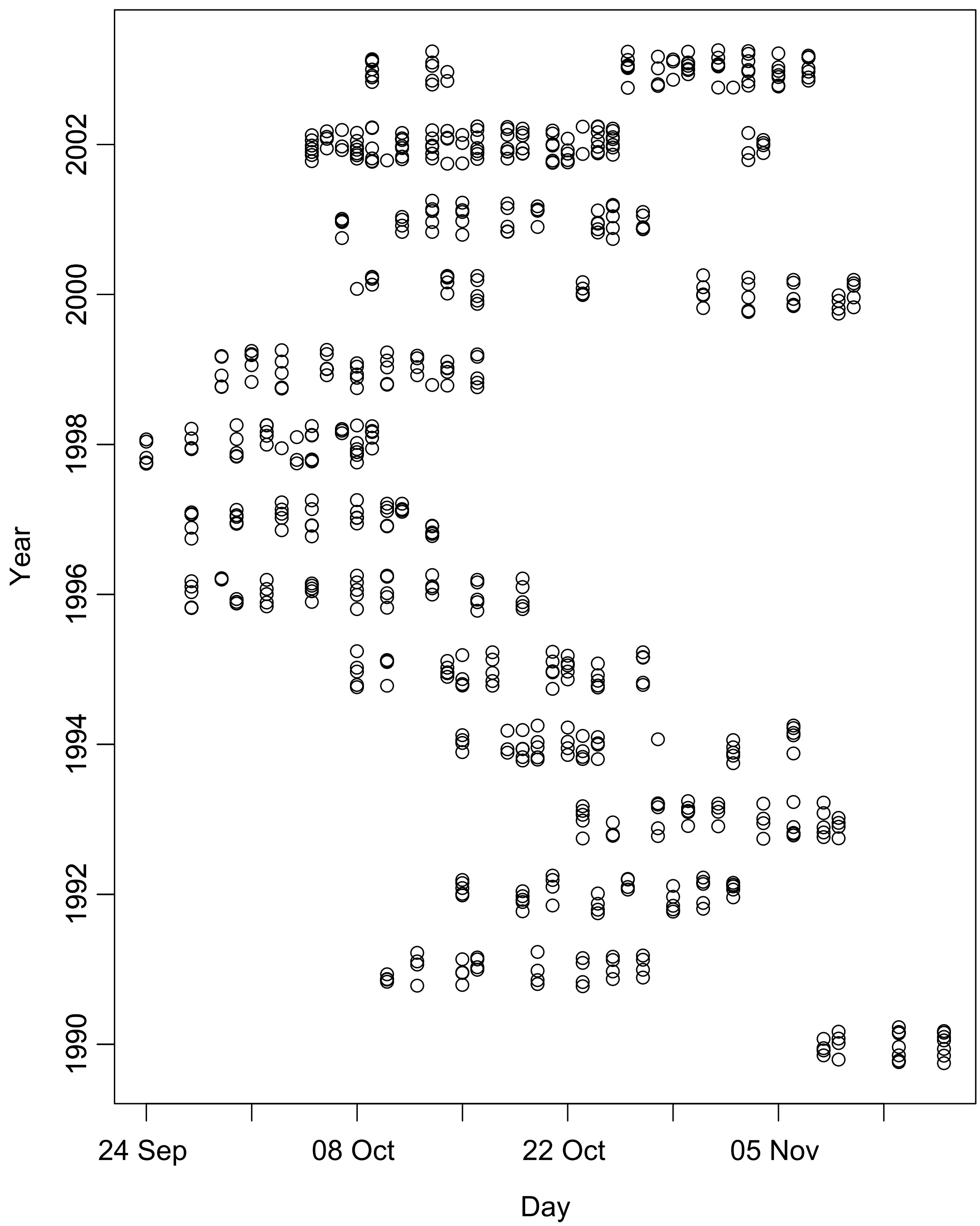


Figure I.9 Annual timing of standardized survey from 1990 to 2003.

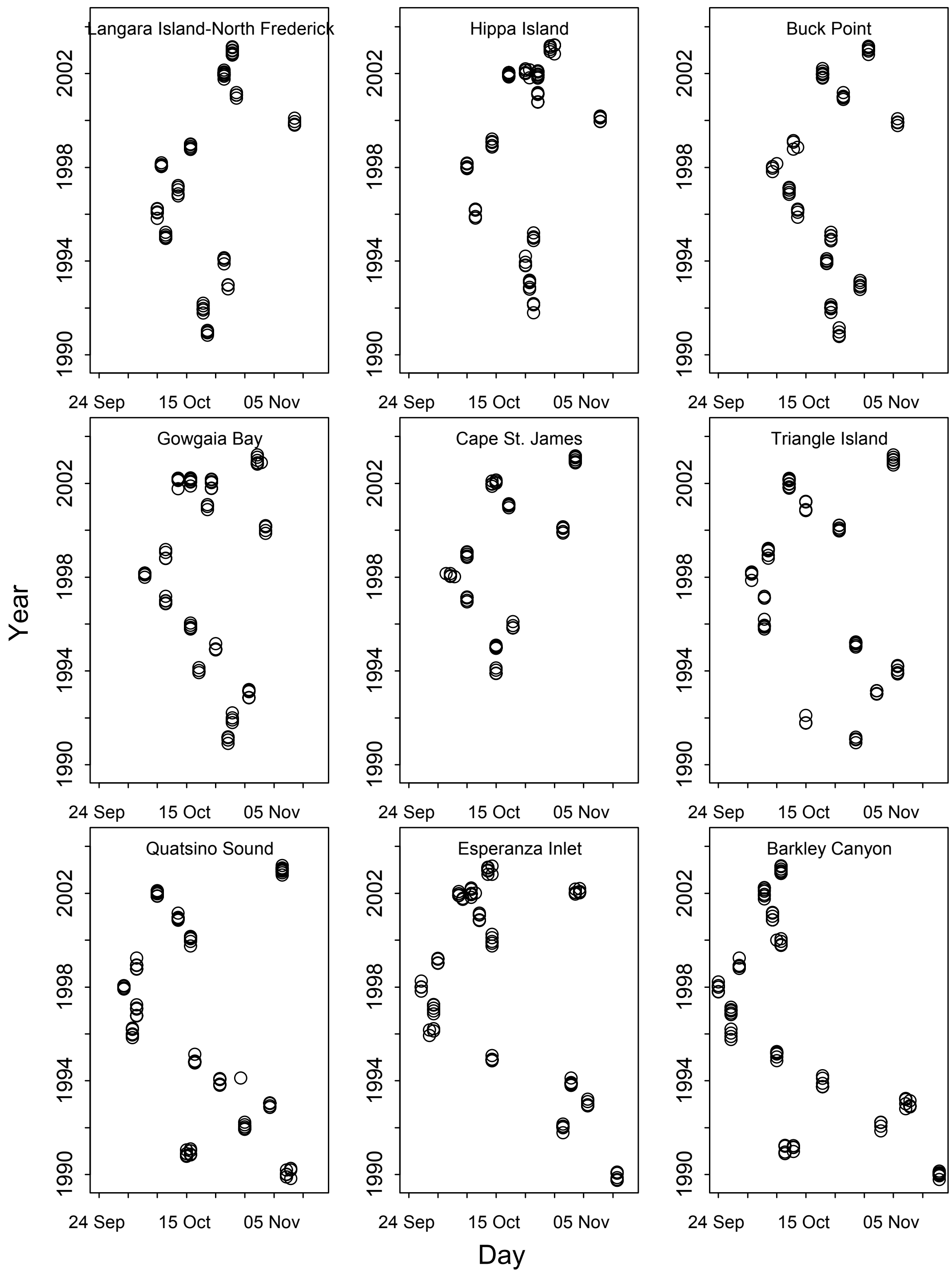


Figure I.10 Annual timing of standardized survey sets by locality from 1990 to 2003.

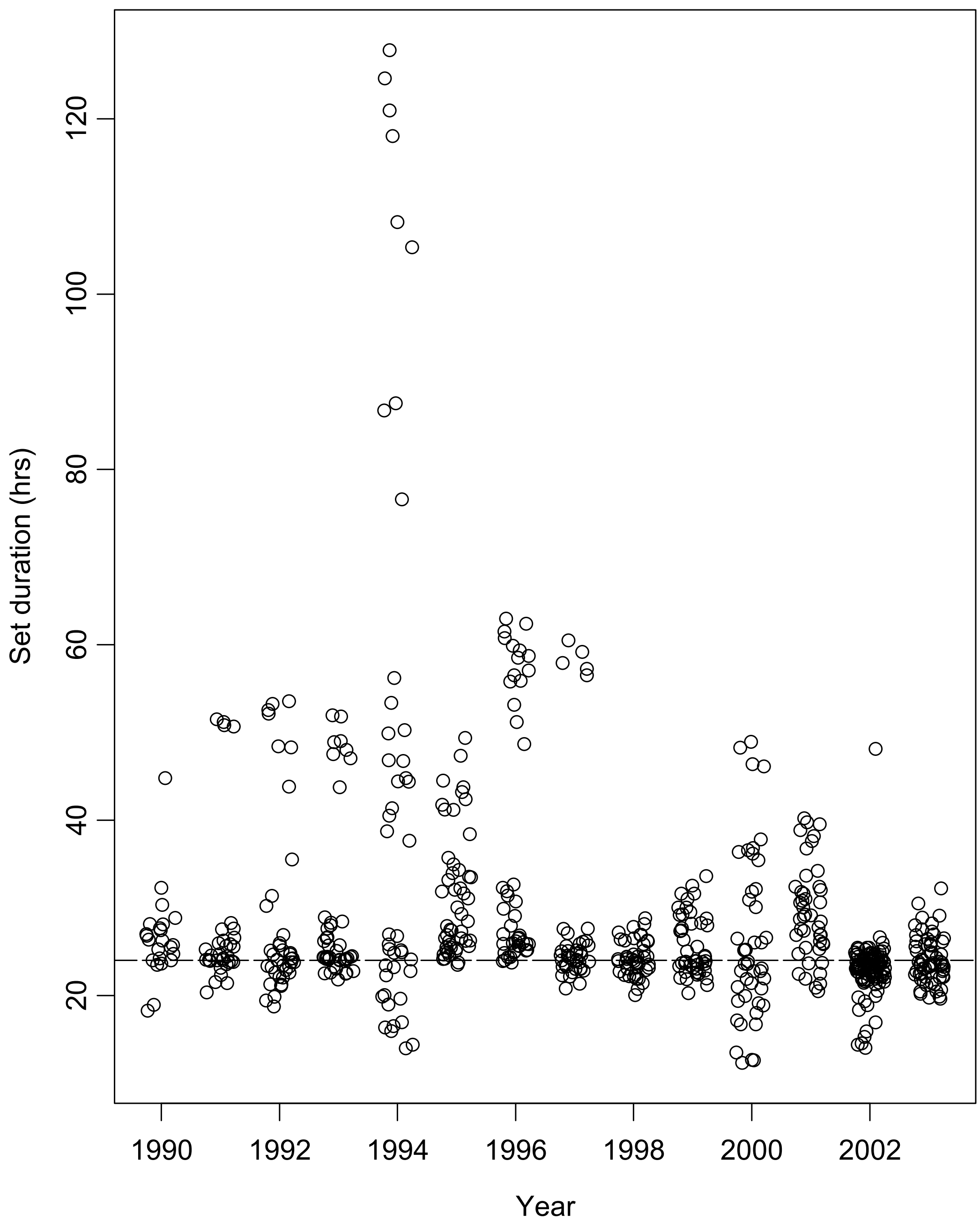


Figure I.11 Standardized survey set duration (h) by year. The horizontal dashed line is positioned at the target duration of 24 hours.

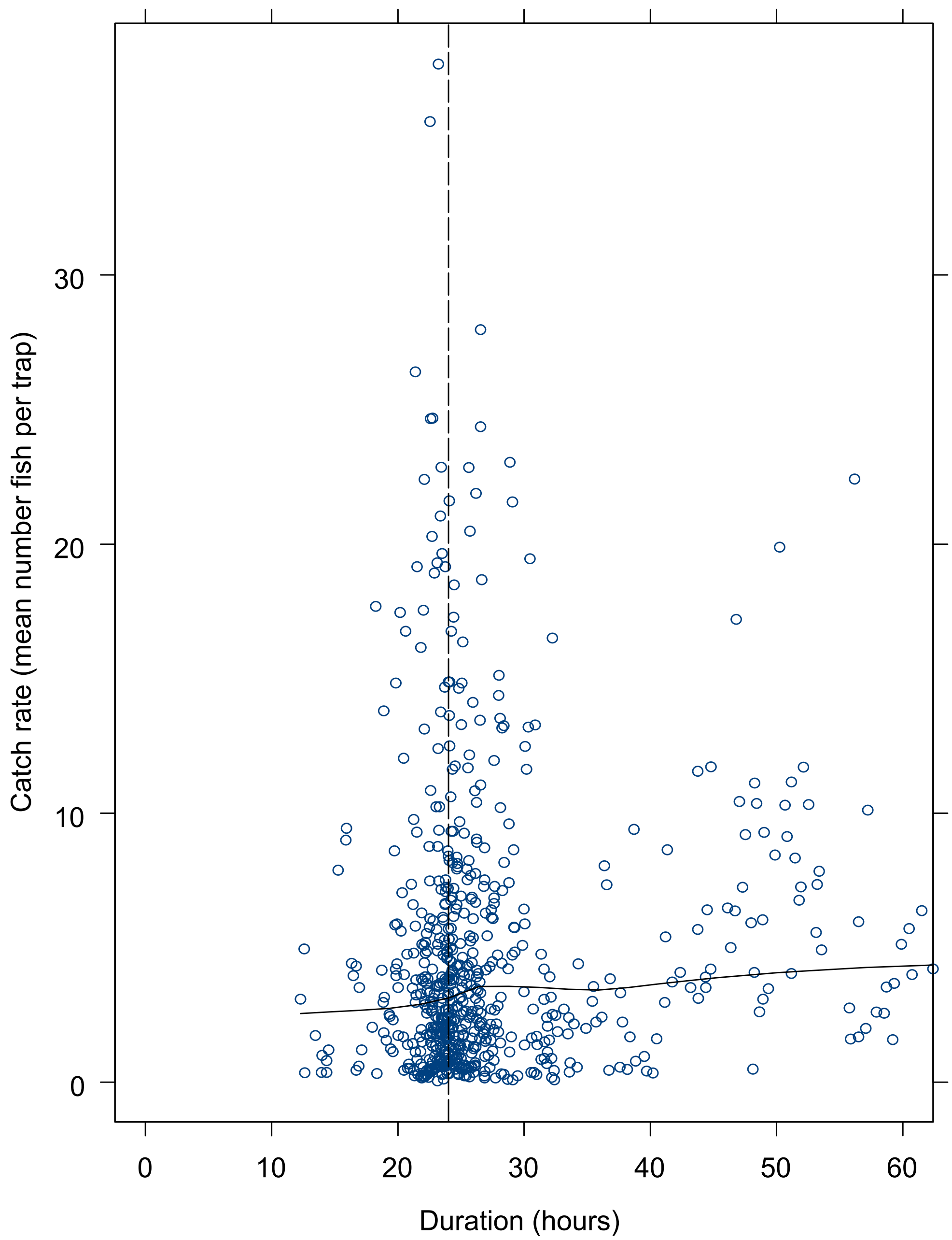


Figure I.12 Catch rate (mean number per trap) as a function of set duration (h). Open circles indicate survey sets. The vertical dashed line is positioned at 24 hours. The solid line represents a loess smoothing trend of the relationship between survey catch rate and set duration.

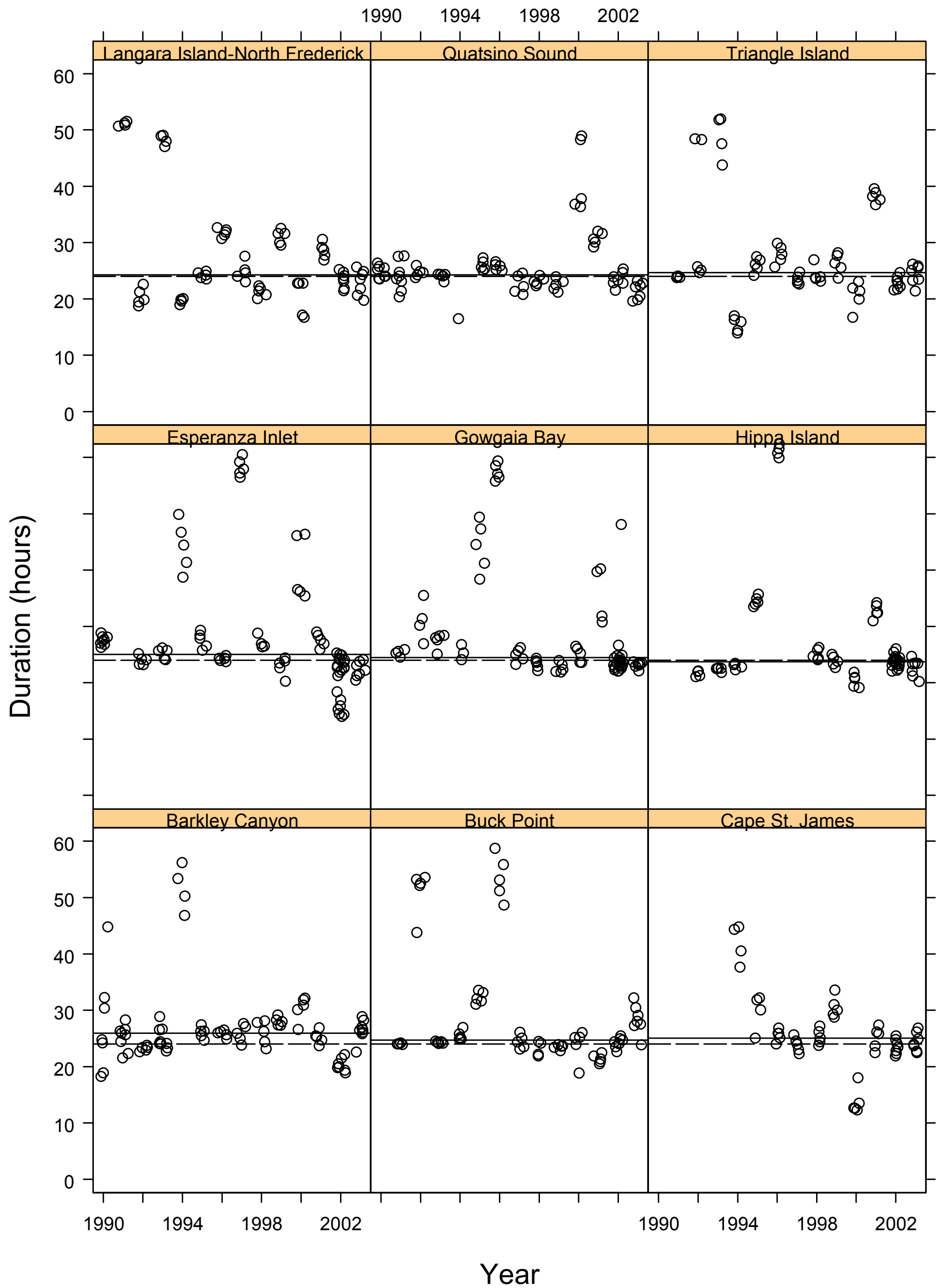


Figure I.13 Standardized set duration by year and survey locality. Open circles represent survey sets. Within each figure panel, the horizontal dashed line is positioned at 24 hours, while the horizontal solid line is the median set duration.

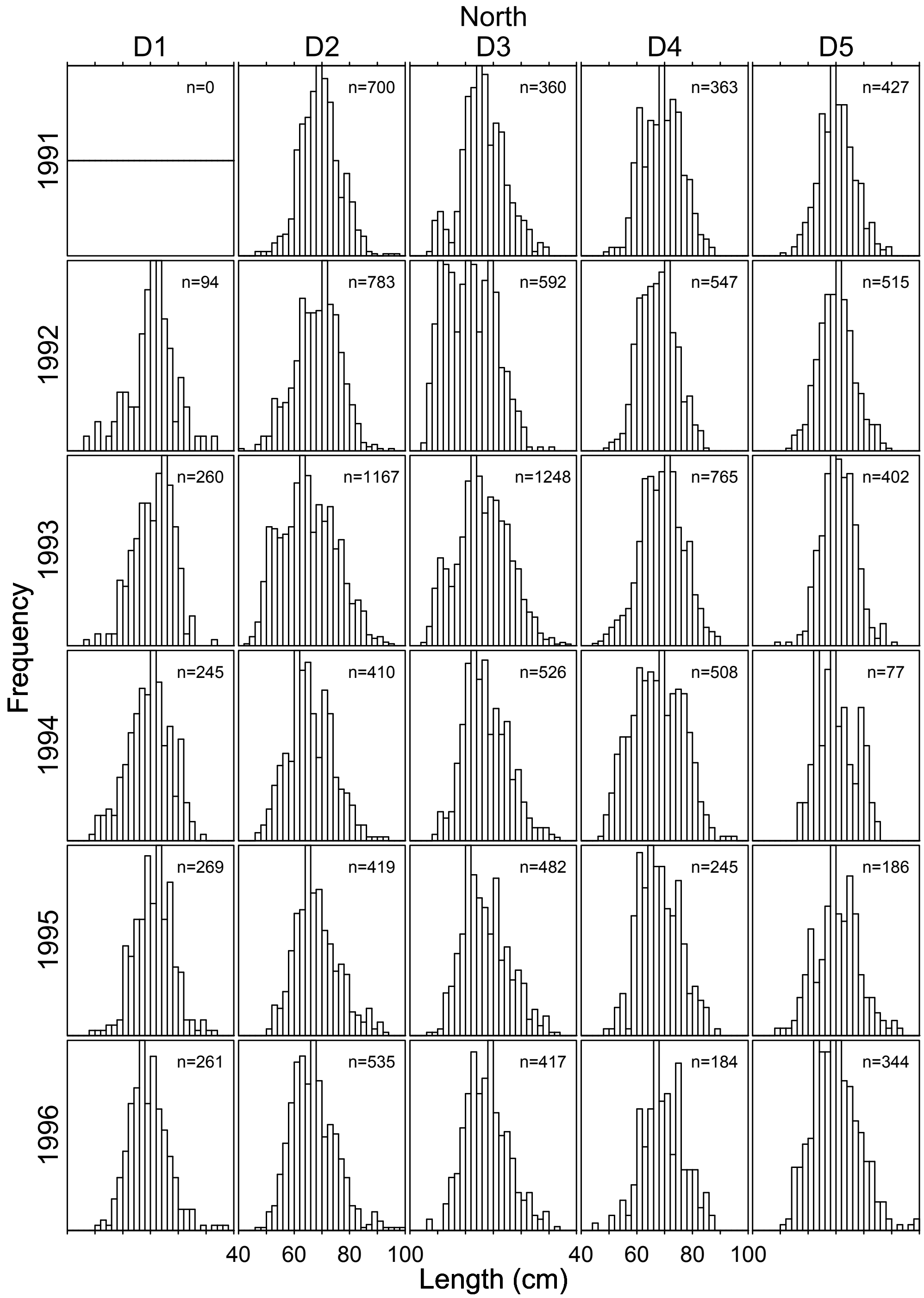


Figure I.14 Length frequency histograms for sablefish by year and depth stratum for northern survey localities.

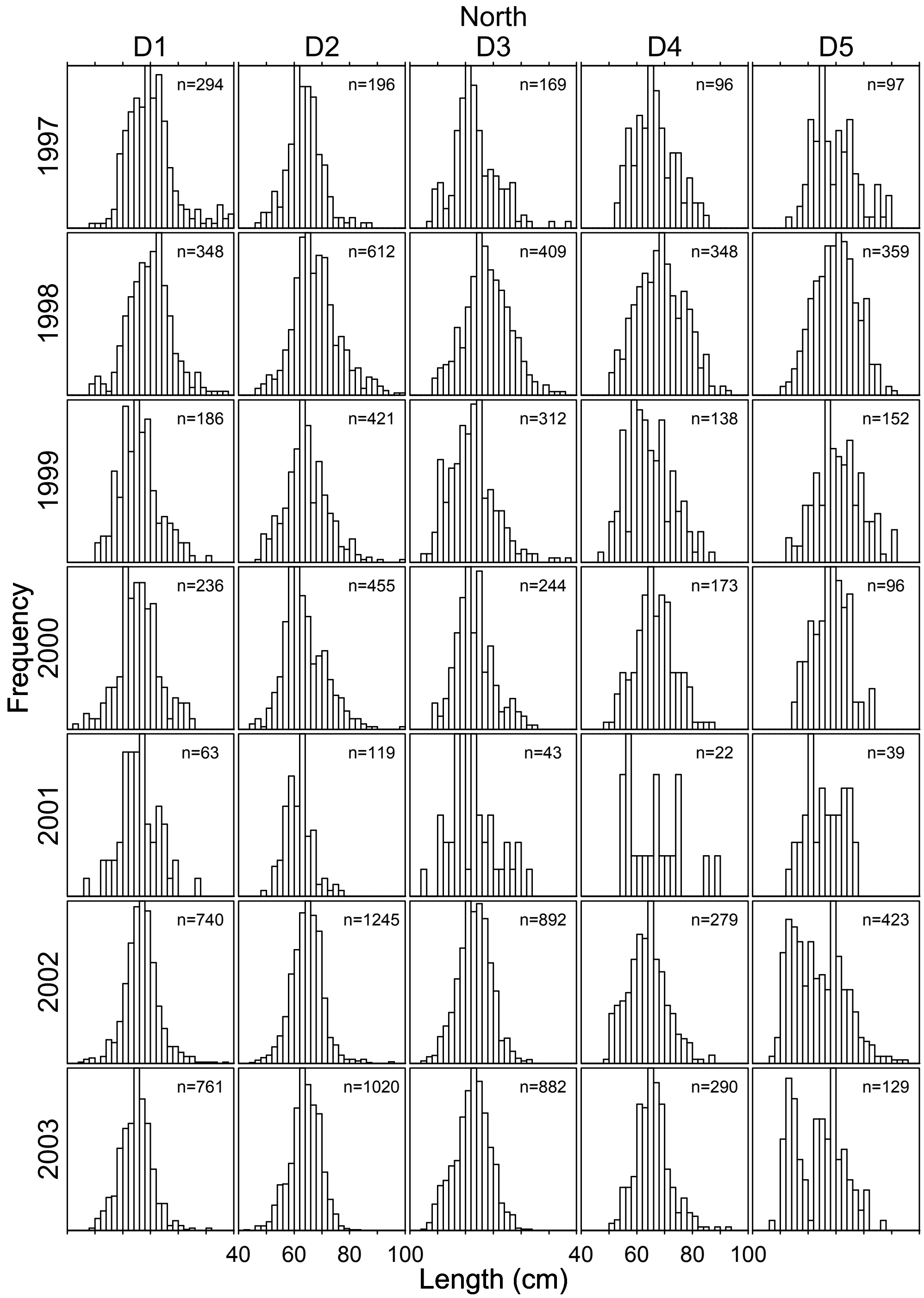


Figure I.14 Continued.

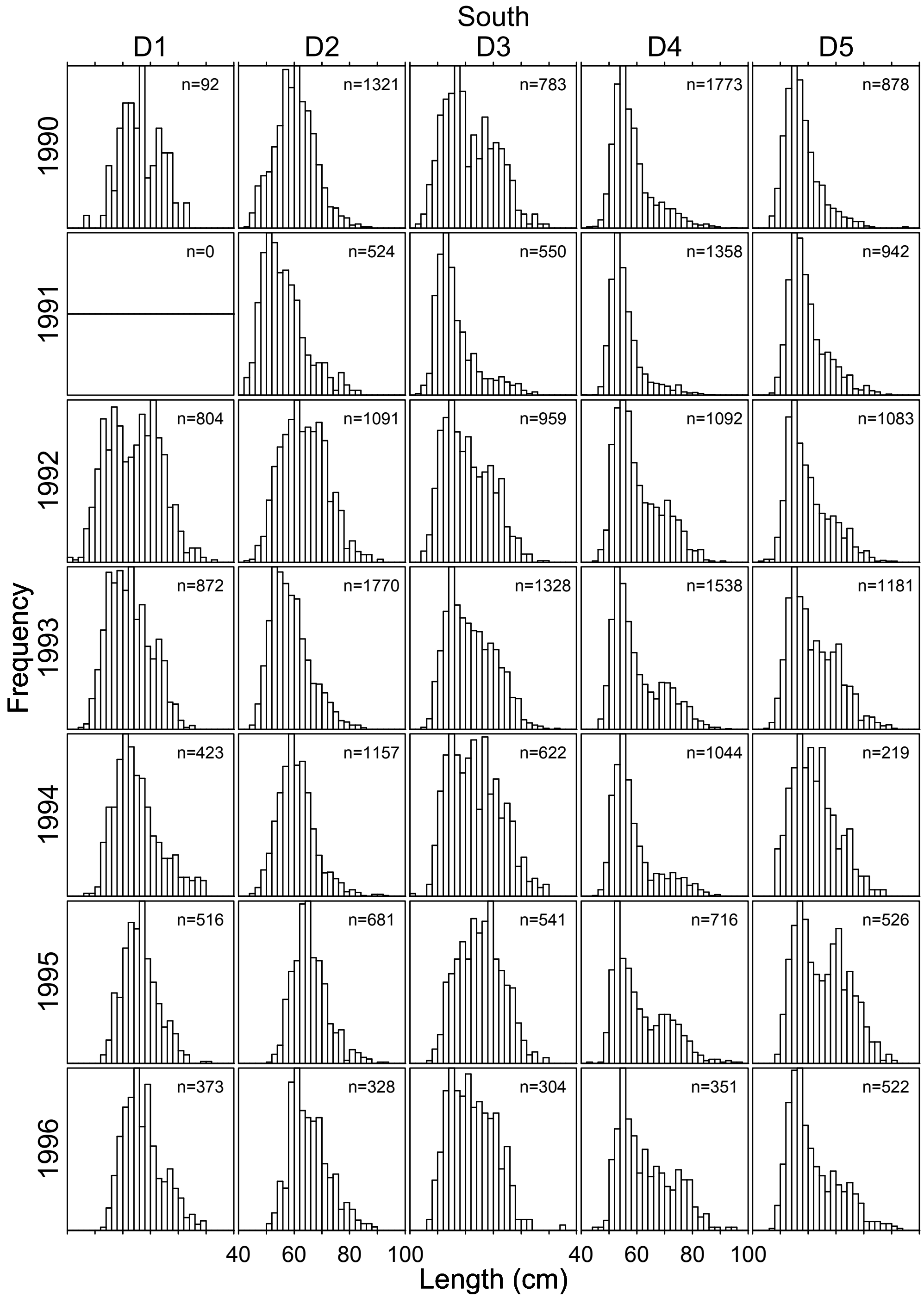


Figure I.15 Length frequency histograms for sablefish by year and depth stratum for the southern survey localities.

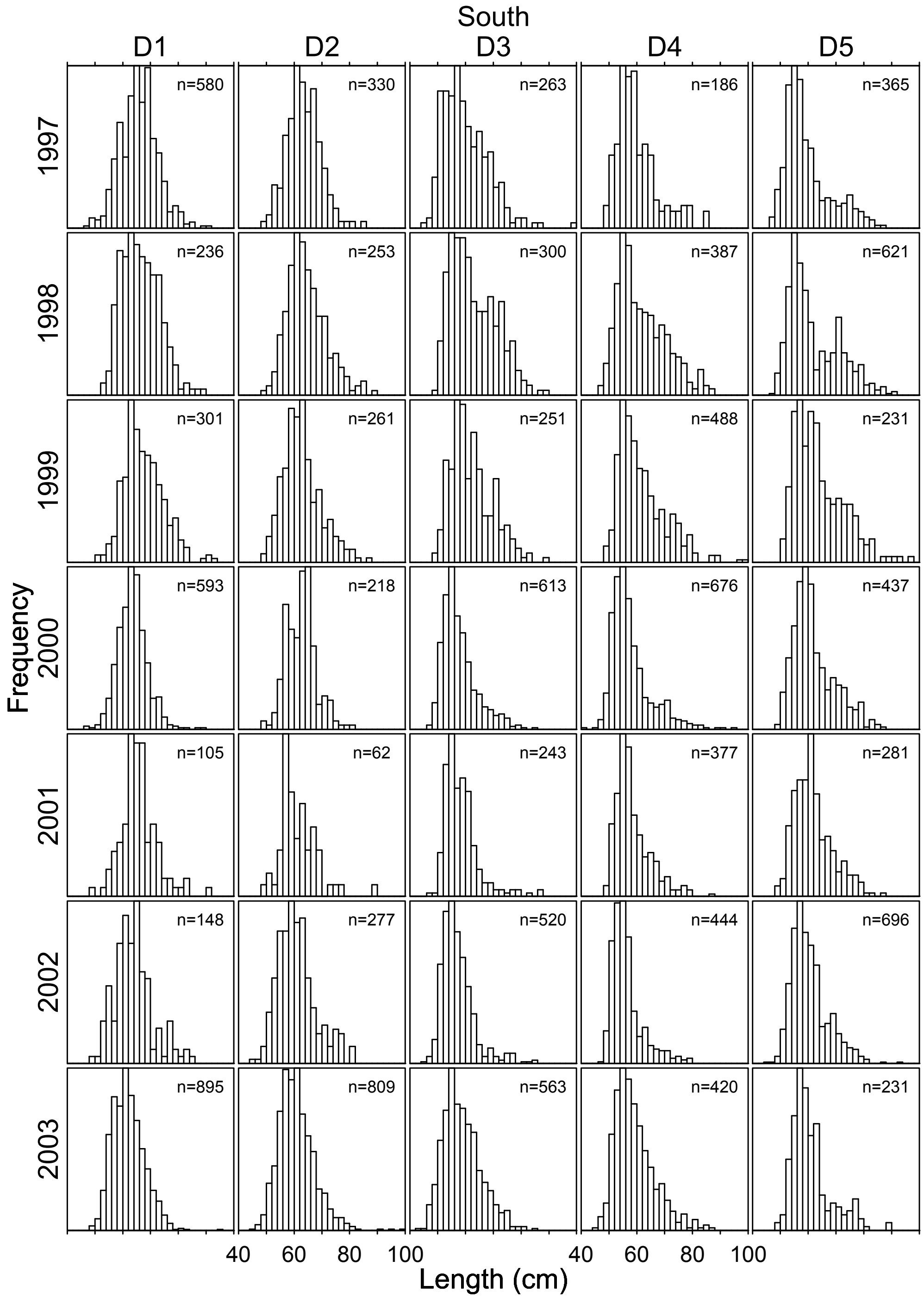


Figure I.15 Continued.

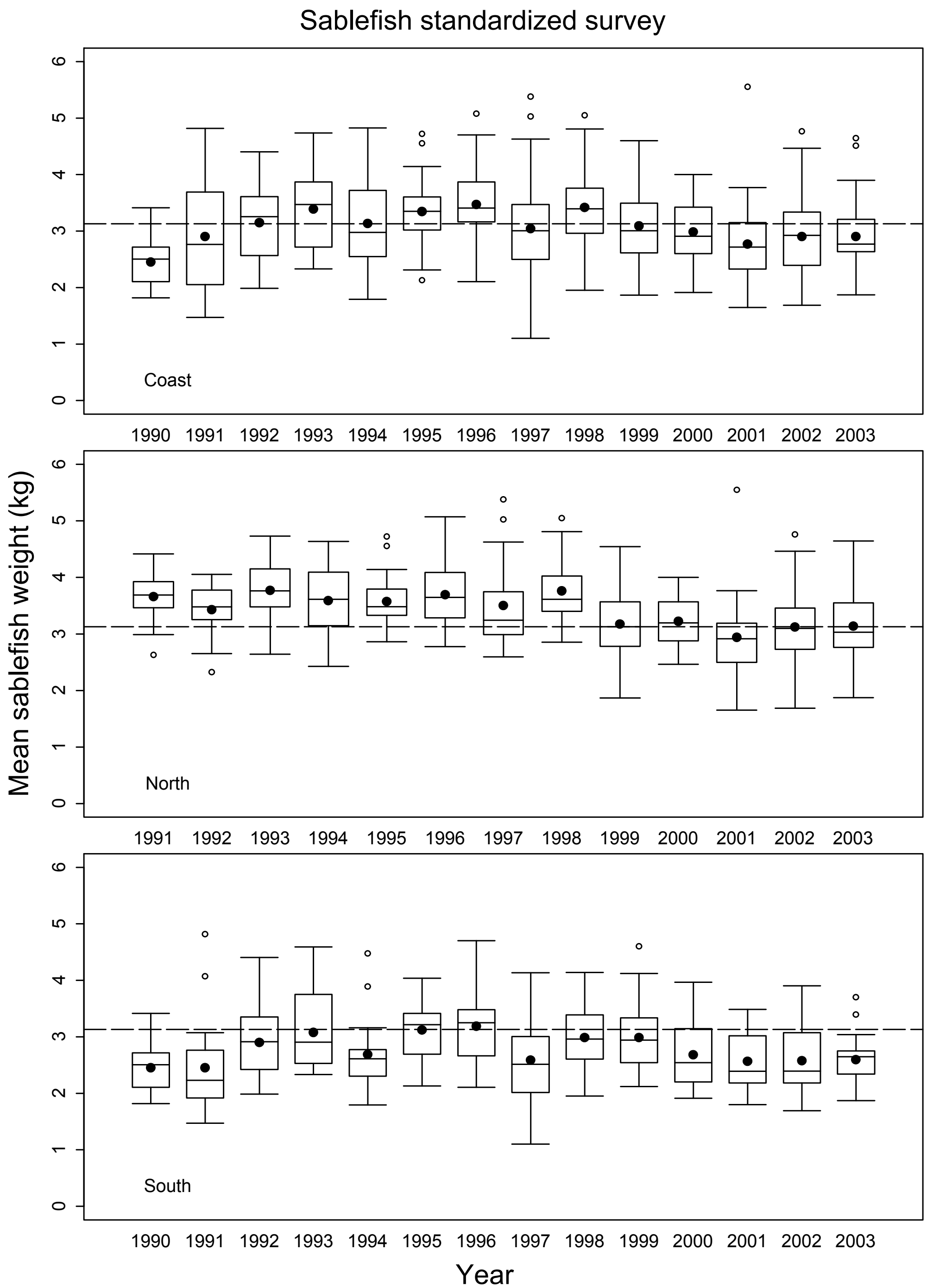


Figure I.16 Boxplots summarizing the distribution of mean sablefish weight among sets for the coast, and north and south stock areas in depth strata 1 through 5. Filled circles indicate the mean over sets. The dashed horizontal line is the global mean weight over years and sets.

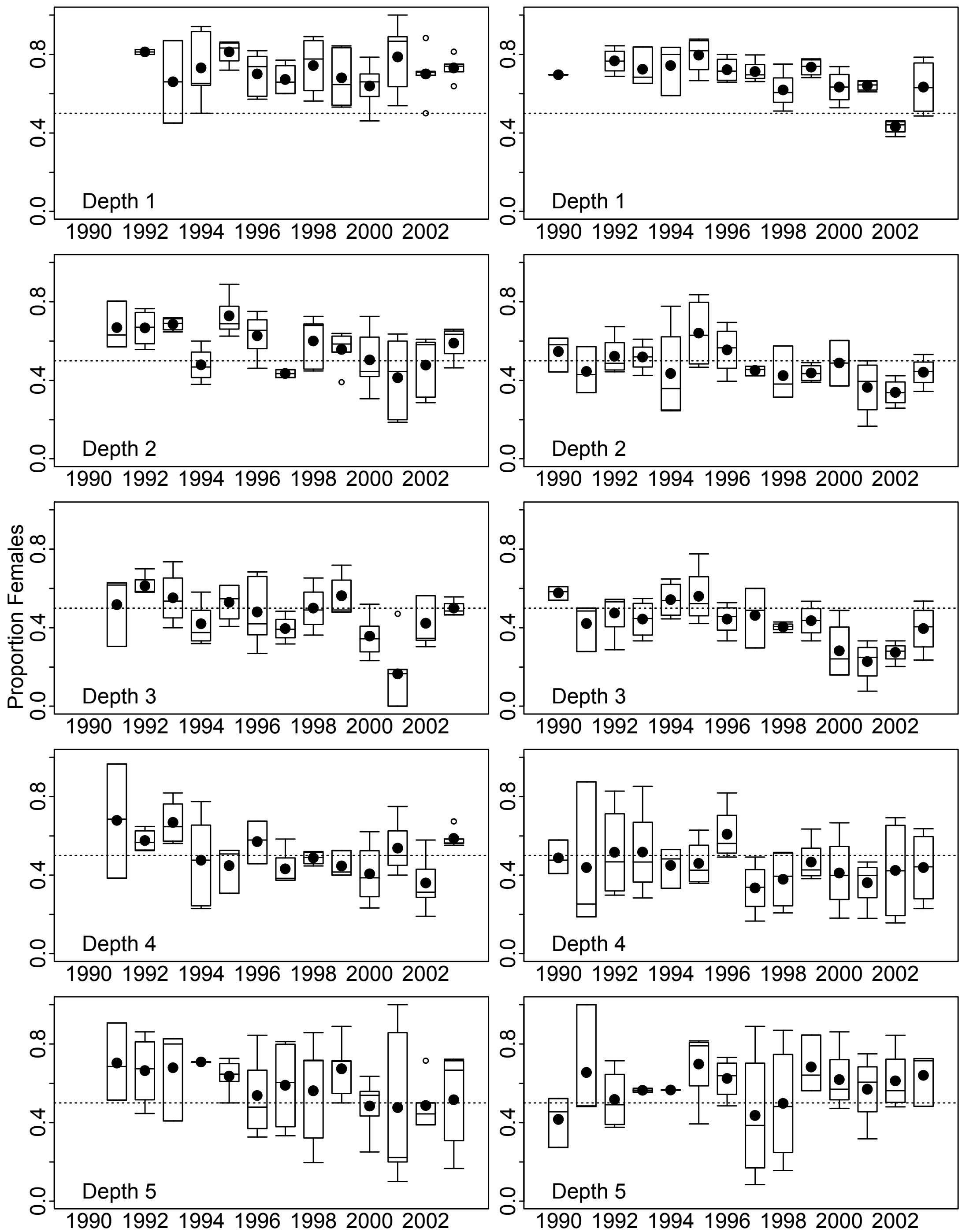


Figure I.17 Proportion of females by year, survey depth stratum and north/south stock areas (left and right panels, respectively). The solid circles overlaid on each boxplot indicate the mean proportion females.

APPENDIX J ANALYSIS OF STANDARDIZED SURVEY DATA

J.1 DATA SELECTION J-1
J.2 MODEL DESCRIPTION J-1
J.3 MODEL RESULTS J-2
J.4 MODEL DIAGNOSTICS J-3
J.5 SUMMARY J-4
J.6 LITERATURE CITED J-5

J.1 Data Selection

Data from the standardized survey were assembled from 1990 to 2003. Fishing event data were included in analyses if the following conditions were met:

- the set was made as part of the standardized survey ([B02_FISHING_EVENT]![REASON.CODE]=13;
- the trap usability code ([B02d_Trap_Specs]![USABILITY_CODE) was 1, indicating that the gear was fishing correctly and was not fouled or holed;
- the depth fished was contained in stratum 1 to stratum 5, as determined by assigning the set to a depth stratum based on the mean of depths ([B02_FISHING_EVENT]![FE_MODAL_BOTTOM_DEPTH]) recorded at one minute intervals during deployment of the gear.

Specific sets were excluded from the analysis as identified in Table I.5 of Appendix I. Sets where the mean depth of the set fell into depth stratum 0, 6 and 7 were not included in the analyses because their occurrence is limited to the 2002 (D6, D7) and 2003 (D0) survey years. One 1994 Esperanza Inlet set previously included in the standardized survey index calculation was retained in the analysis. The mean depth was slightly above the upper bound of depth stratum 1 and the minimum and maximum depths straddled the boundary.

J.2 Model Description

Each standardized set of survey gear consisted of a string of 25 traps. Catch was recorded in numbers of sablefish per trap and aggregate sablefish weight (kg) per trap. The aggregate weight may be an underestimate of the catch as fish may be partially eaten or reduced to frames by amphipod predation in some traps. The survey gear was inspected upon retrieval to determine if each trap was actually fishing ("effective") and not fouled or holed. The observed catch rate for each set was computed by summing the catch of sablefish in each effective trap, C_{tijk}, and dividing by the number of effective traps, n_{tijk}

(1) $$U_{tijk} = \frac{\sum_{l=1}^{n_{tijk}} C_{tijkl}}{n_{tijk}} \quad ,$$

where U_{tijk} is the catch rate for set *k* in depth stratum *j* of survey locality *i* for year *t*. The value U_{tijk} is the mean catch rate per trap for the set, but is hereafter referred to as the catch per unit effort (CPUE) for the set. Note that the number of effective traps may differ from 25 traps due to miscounting of traps on deployment or to detection of fouled or holed gear upon retrieval.

A general linear model (GLM) was used to standardize CPUE data over the survey time series and to separate effects due to locality and depth. The observations can be described by the linear statistical model

(2) $$U_{tijk} = \mu + \alpha_t + \beta_i + \gamma_j + \varepsilon_{tijk} \quad ,$$

where μ is the overall mean effect, α_t is the effect of the *t*th level of the year factor, β_i is the effect of the *i*th level of the depth factor, γ_j is the *j*th effect of the locality factor, and ε_{tijk} is a random error component. Random errors were assumed to be normally distributed with mean 0 and variance σ^2. This main effects model does not include interaction terms of the form $(\beta\gamma)_{ij}$ since there are very few replicates by depth and locality (see Appendix I). The factors are assumed fixed. The model is over-parameterized, so that constraints must be imposed to obtain parameter estimates. The so-called corner point constraints are applied here, so that the first level of each factor is set to 0, i.e., $(\alpha_1 = 0, \beta_1 = 0, \gamma_1 = 0)$, and the remaining levels of each factor represent the additive effects of each level relative to the first "reference" level. The overall mean, μ, is then the model estimate of the catch rate for the first year in the time series, the first level of the locality factor, and the shallow depth stratum.

J.3 Model Results

The model was applied to the north and south stock areas independently, and to the combined data to obtain results for the coast. For the north area, the reference CPUE was selected as year 1991, depth stratum 1, and the Langara Island-North Frederick survey locality. Similarly, the reference level for the south was defined as year 1990, depth stratum 1, and the Triangle Island survey locality. Catch rates in units of mean number per trap were adopted to avoid bias in weight measurements due to predation on fish in traps by, for example, amphipods. Initial trials of the model suggested that the catch rate observations should be square root transformed to satisfy the assumptions of homogeneity and normally distributed errors. Experimentation with a natural logarithm transform of catch rates and with Poisson distributed errors failed to produce superior model diagnostics (not shown here).

The Analysis of Variance (ANOVA) tables and related statistics are shown in Table J.1 for the north, south, and coast areas. The tables show the sequential (Type I) sums of squares. For the south and coast-wide model fits, the locality factor is significant; differences among localities are not significant for the north model fit. The locality factor could be removed from the north model, however it was retained for consistency with other model fits and in practice there is no real penalty for leaving it in the simple additive model. Graphical representations of the contribution of each factor to the predicted values are shown in Figure J.1 to Figure J.3 for the north, south, and coast data, respectively. Each figure panel represents the fitted effects for a factor in the main effects model. Factor effects have been centered about zero. The broken line for each effect indicates two standard errors. The rugplot at the base of each plot indicates the locations of observed values of the response variable, randomly jittered to expose the density of observations. Within each figure, the y-axis has been set to the same vertical scale on each panel to allow visual judgments of the relative importance of each factor to the fit. All models explain between 56 (north) and 52 (coast) percent of the observed variation.

The highest catch rates in the north area were achieved for sets conducted in depth stratum 2. The lack of dependence on locality for the north stock area is clearly evident. For the south stock area, the year effect is greatest and the locality effect appears to contribute more to the fit than the depth effect. The fit appears better for the north and coast-wide models than for the south stock area model, primarily due to lack of fit at Barkley Canyon where there is interaction between depth and year.

Table J.2 summarizes the year effects for each of the model fits. The estimated coefficients for each model and associated standard errors are listed, along with the coefficients adjusted for the reference levels of depth and locality by adding the model intercept as the first year effect. Both are provided on the square root CPUE scale. The marginal means adjusted for all levels of depth and locality are also listed with associated standard errors on the square root CPUE scale.

J.4 Model diagnostics

Diagnostics for the indexing survey model fits include trellis plots of the predicted values and residuals against fitted values for the coast wide model, and a normal probability plot of the Studentized residuals for north, south, and coast models (Figure J.4 to Figure J.6). Trellis plots for fitted values and residuals are arrayed by locality and depth stratum. The observations, or residuals, are shown using open circles. In the case of the model fit plots (Figure J.4), the solid line superimposed on each panel joins the model estimates for each year. The solid line on the residual plot panels (Figure J.5) is a loess smooth trend line to help diagnose pattern in the residuals. In general, the detailed model diagnostics indicate that interaction terms would likely increase the amount of variation explained by the model. However, such analyses will necessarily await the accumulation over time of replicates for each combination of model factors, or an alternative survey design such as the stratified random design conducted as a pilot study in 2003 (Appendix G).

Normal probability plots of the Studentized residuals for model fits corresponding to north, south, and coast data are shown in the three panels of Figure J.6. A simulation envelope (dotted lines) set at the 95 percent probability level is used to enhance each plot. Residuals that do not conform to a normal distribution fall outside the envelope. There is evidence of lack of fit in the tails of the residuals that was not present prior to the addition of the 2003 survey data (see Kronlund et al. 2003).

J.5 Summary

If the survey catch rates are assumed to be proportional to stock abundance, the year effects (α_t) from the GLM analysis can be utilized as a stock index (Hilborn and Walters 1992). Figure J.7 shows a plot of the marginal (least squares) means for the north, south, and coast-wide model fits (Table J.2). The marginal means are the year effects averaged over all levels of other factors present in the model fit, and are directly proportional to the year effects for main effects models. The estimates have been back-transformed to the original units of mean number per trap. The vertical line segments indicate plus or minus two standard errors obtained by back-transforming the endpoints calculated on the square root scale, although these limits likely underestimate the true variability.

The design of the indexing survey lacks the replication within each combination of locality and depth stratum required to assess interactions among years, localities, and depth. In particular, the diagnostic plots suggest a year by depth interaction which implies that the trend of the abundance index may depend on depth stratum. These interactions might alter the trajectory of the index, or may give insight into different behavior in the time series among locations and by depth. Nevertheless, the main effects model explained at least 52 percent of the observed variability and the model fits were adequate. Trends in the marginal means by all areas are consistent with those indicated by the exploratory analysis of the observed survey data (Appendix I). The strong positive signal arising from the 2003 survey data is reflected in the index.

Placement of survey sets within depth strata at the discretion of the fishing master has likely produced a positive bias in observed catch rates over what would have been achieved by random set positions. This issue is not important to the purpose of developing a relative abundance index if bias introduced by fishing masters has been similar over time. The strengths of the survey are the relative consistency in the conduct of standardized fishing over time and the broad geographic and depth coverage. The credibility of survey catch rates as an abundance index is reinforced by similarities in the time trends in catch rates from 1990 to 2003 among most localities and within most depth strata (Appendix I).

J.6 Literature Cited

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York. xiii+570 p.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

Table J.1 ANOVA tables for main effects model with catch rates in units of mean number per trap.

Main effects normal-theory model for North

Terms	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
yearFact	12	105.4827	8.790227	22.69190	0.0000000
depthFact	4	37.8846	9.471156	24.44971	0.0000000
locality	4	0.2995	0.074866	0.19327	0.9418079
Residuals	289	111.9508	0.387373		

Residual standard error: 0.6224 on 289 degrees of freedom
Multiple R-Squared: 0.562
F-statistic: 18.54 on 20 and 289 degrees of freedom, the p-value is 0

Main effects normal-theory model for South

Terms	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
yearFact	13	139.7641	10.75108	18.90177	0.0000000
depthFact	4	2.2064	0.55159	0.96977	0.4244598
locality	3	42.0429	14.01430	24.63893	0.0000000
Residuals	274	155.8477	0.56879		

Residual standard error: 0.7542 on 274 degrees of freedom
Multiple R-Squared: 0.5414
F-statistic: 16.18 on 20 and 274 degrees of freedom, the p-value is 0

Main effects normal-theory model for Coast

Terms	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
yearFact	13	245.1372	18.85670	35.61605	0.000000e+000
depthFact	4	19.9180	4.97949	9.40513	2.270973e-007
locality	8	71.1140	8.88925	16.78978	0.000000e+000
Residuals	579	306.5481	0.52944		

Residual standard error: 0.7276 on 579 degrees of freedom
Multiple R-Squared: 0.523
F-statistic: 25.4 on 25 and 579 degrees of freedom, the p-value is 0

Table J.2 Year effects for the main effects model fits to north, south, and coast areas.

Years	Model Coefficients	Std. Err.	Coef+Intercept (sqrt scale)	Coef+Intercept (numbers/trap)	Marginal Mean (sqrt scale)	Std. Err.
North						
1991	2.394	0.211	2.394	5.730	2.431	0.206
1992	-0.120	0.233	2.274	5.171	2.312	0.176
1993	0.318	0.231	2.712	7.356	2.750	0.173
1994	-0.630	0.231	1.764	3.111	1.802	0.170
1995	-0.886	0.223	1.508	2.273	1.545	0.159
1996	-0.796	0.222	1.598	2.554	1.636	0.157
1997	-1.117	0.230	1.277	1.630	1.314	0.170
1998	-0.604	0.223	1.790	3.204	1.828	0.159
1999	-1.152	0.222	1.242	1.543	1.280	0.157
2000	-1.097	0.221	1.297	1.681	1.334	0.157
2001	-1.807	0.223	0.587	0.344	0.624	0.159
2002	-0.826	0.206	1.567	2.457	1.605	0.133
2003	0.327	0.219	2.721	7.405	2.759	0.153
South						
1990	2.256	0.221	2.256	5.092	2.711	0.194
1991	-0.171	0.234	2.086	4.351	2.540	0.204
1992	0.603	0.233	2.860	8.177	3.314	0.201
1993	0.855	0.224	3.111	9.681	3.566	0.192
1994	-0.193	0.236	2.064	4.259	2.518	0.205
1995	-0.292	0.233	1.965	3.861	2.420	0.201
1996	-0.814	0.233	1.442	2.080	1.897	0.201
1997	-0.978	0.234	1.279	1.635	1.733	0.201
1998	-0.823	0.237	1.433	2.054	1.888	0.205
1999	-0.962	0.233	1.295	1.676	1.749	0.201
2000	-0.532	0.234	1.725	2.975	2.180	0.202
2001	-1.404	0.233	0.853	0.727	1.307	0.201
2002	-1.245	0.211	1.012	1.023	1.466	0.176
2003	0.140	0.233	2.397	5.745	2.852	0.201
Coast						
1990	2.209	0.199	2.209	4.880	2.473	0.186
1991	-0.054	0.203	2.155	4.646	2.420	0.165
1992	0.330	0.197	2.539	6.446	2.803	0.155
1993	0.683	0.192	2.892	8.365	3.156	0.151
1994	-0.333	0.196	1.876	3.519	2.140	0.154
1995	-0.531	0.192	1.678	2.815	1.942	0.148
1996	-0.706	0.192	1.503	2.260	1.767	0.148
1997	-0.980	0.196	1.229	1.511	1.493	0.153
1998	-0.619	0.193	1.590	2.529	1.854	0.149
1999	-0.974	0.192	1.235	1.526	1.499	0.148
2000	-0.745	0.192	1.464	2.142	1.728	0.148
2001	-1.539	0.192	0.670	0.449	0.934	0.149
2002	-0.913	0.179	1.296	1.679	1.560	0.131
2003	0.330	0.191	2.539	6.448	2.803	0.146

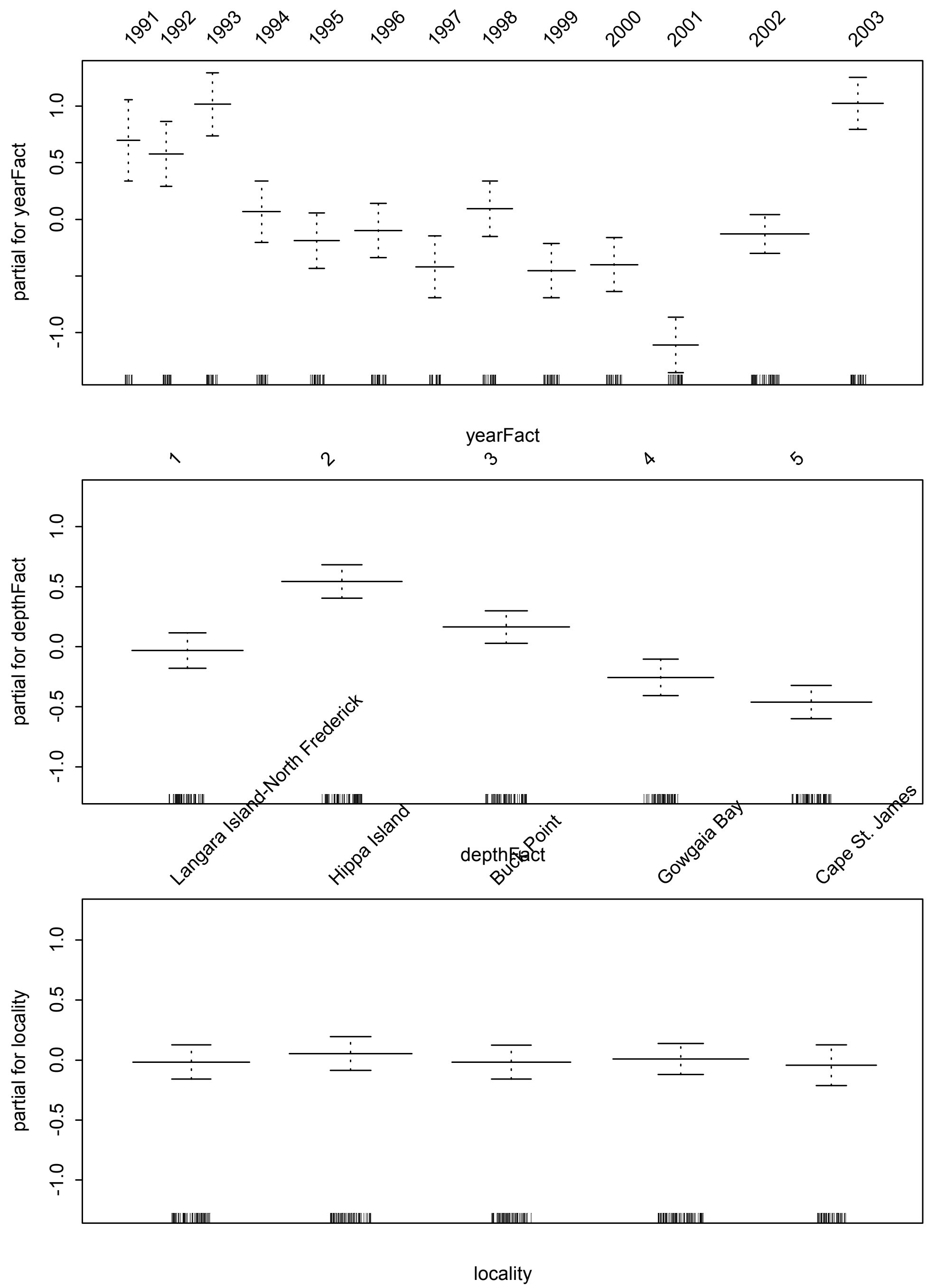


Figure J.1 Contributions to the standardized survey fit by model factor for the north stock area.

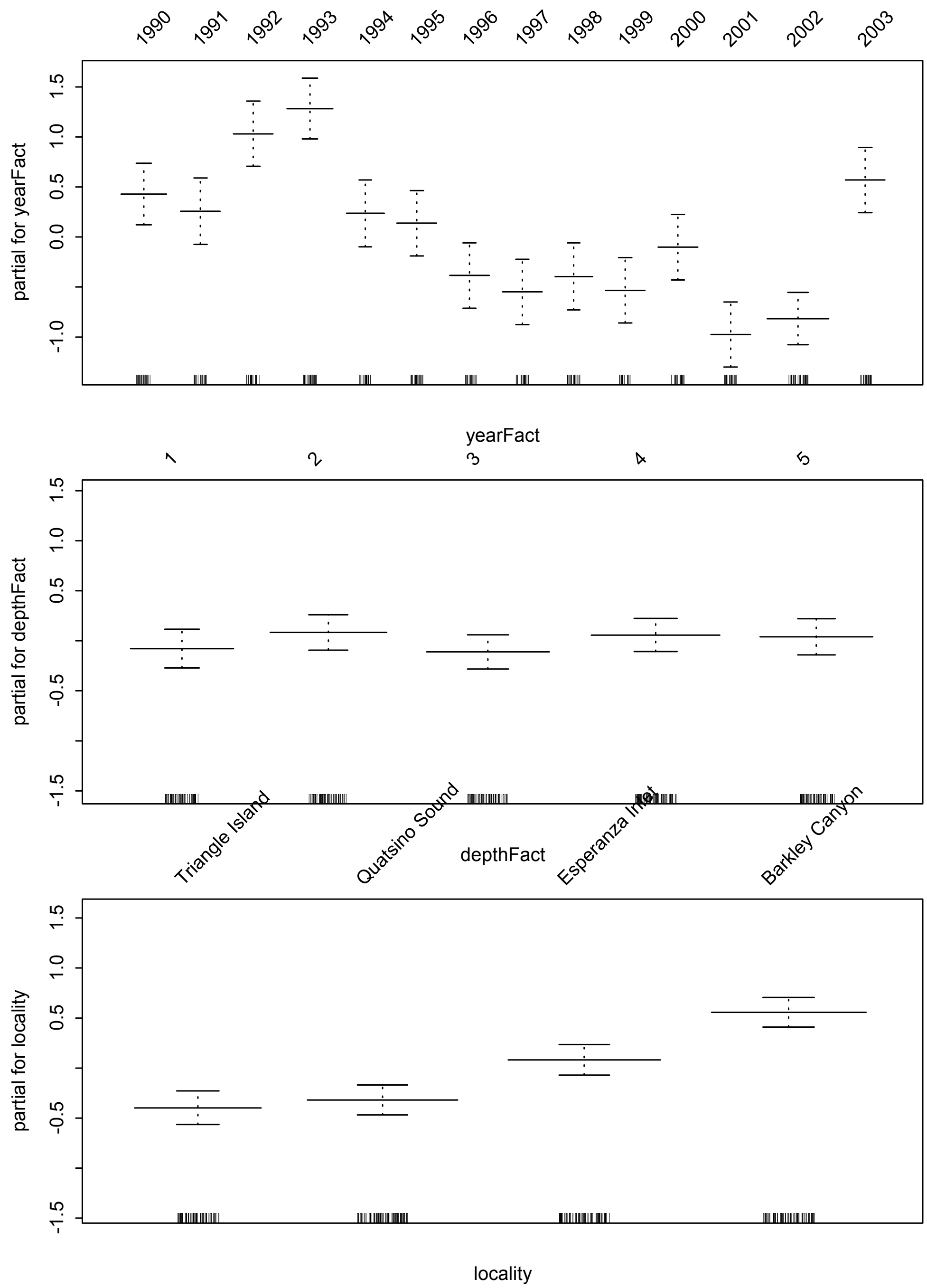


Figure J.2 Contributions to the standardized survey fit by model factor for the south stock area.

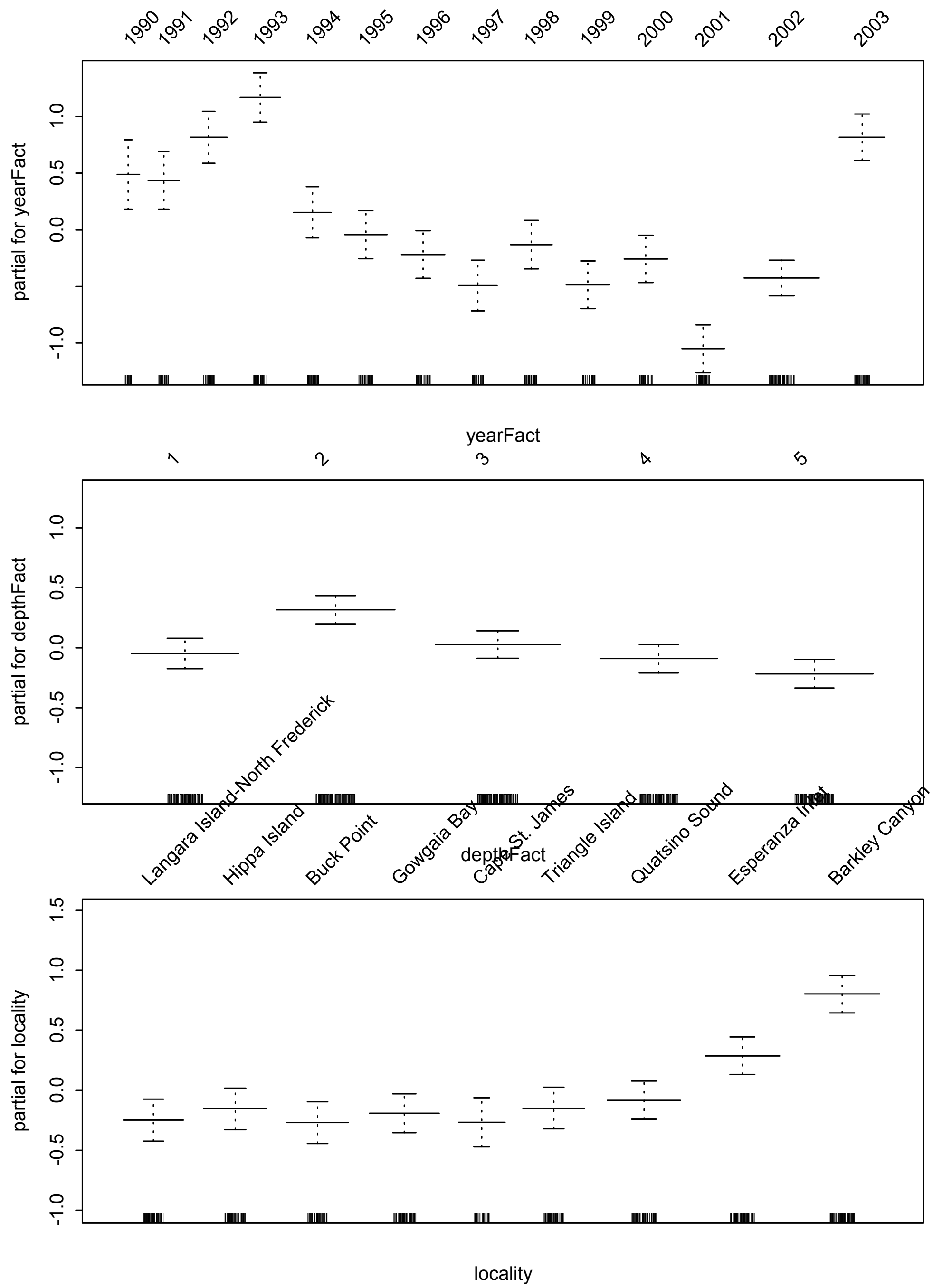


Figure J.3 Contributions to the standardized survey fit by model factor for the coast.

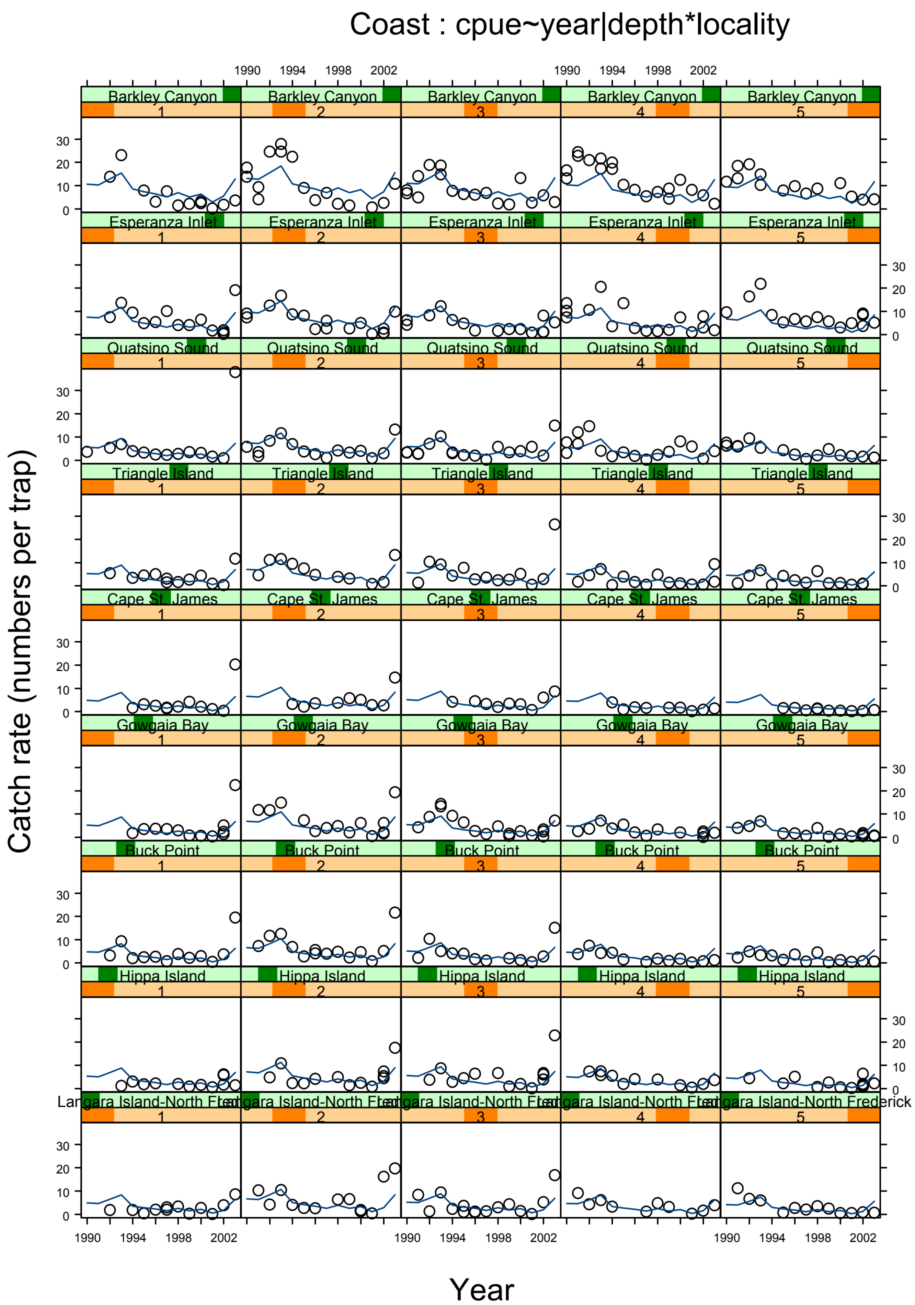


Figure J.4 Fitted and observed indexing survey catch rates for the coast.

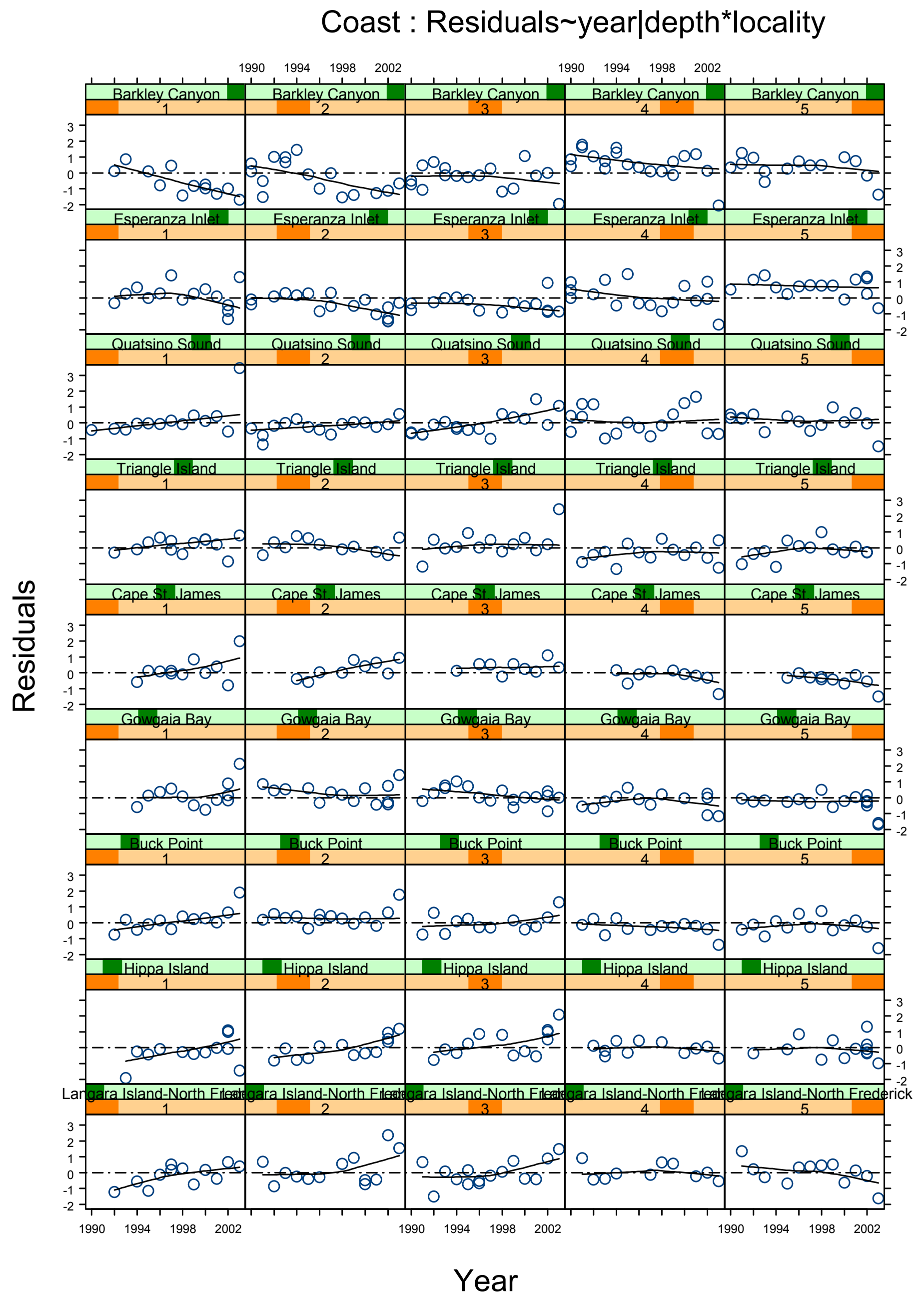


Figure J.5 Residuals for the indexing survey model for the coast.

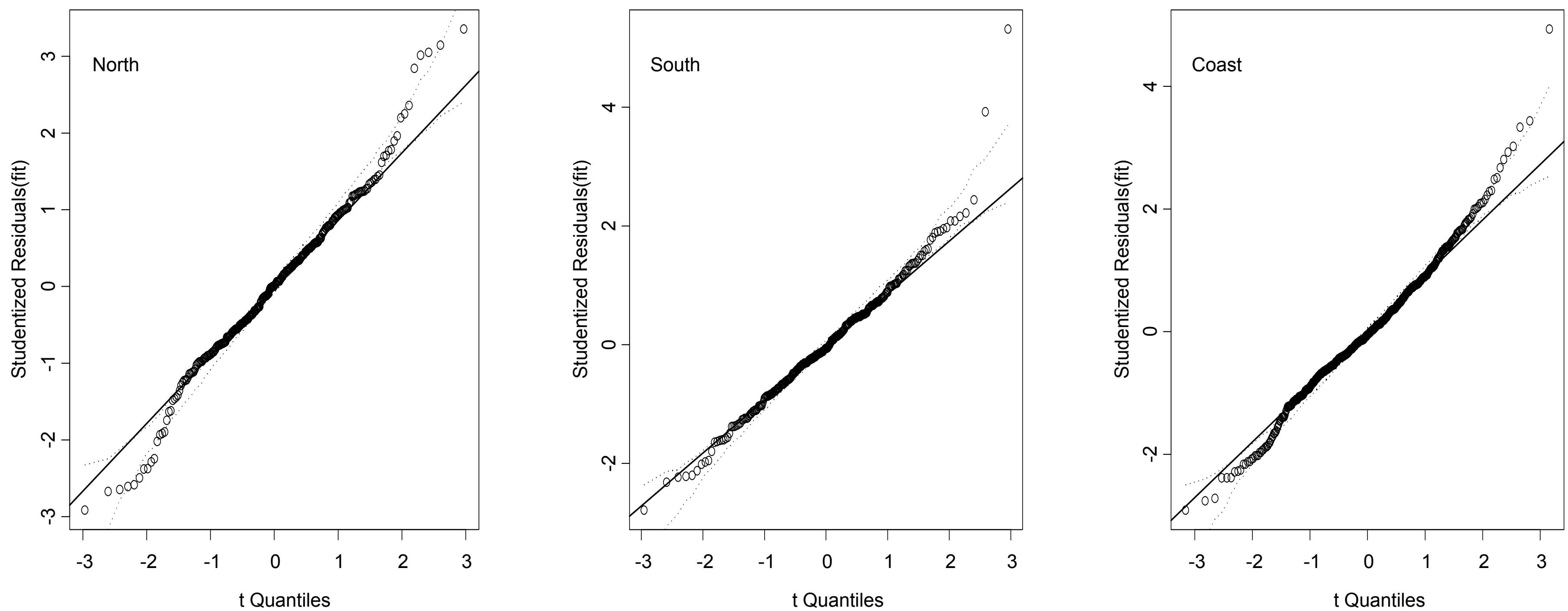


Figure J.6 Quantile-normal plots of the studentized residuals for the north, south, and coast model fits. The dotted lines indicate a 95 percent simulation envelope to detect the presence of outliers.

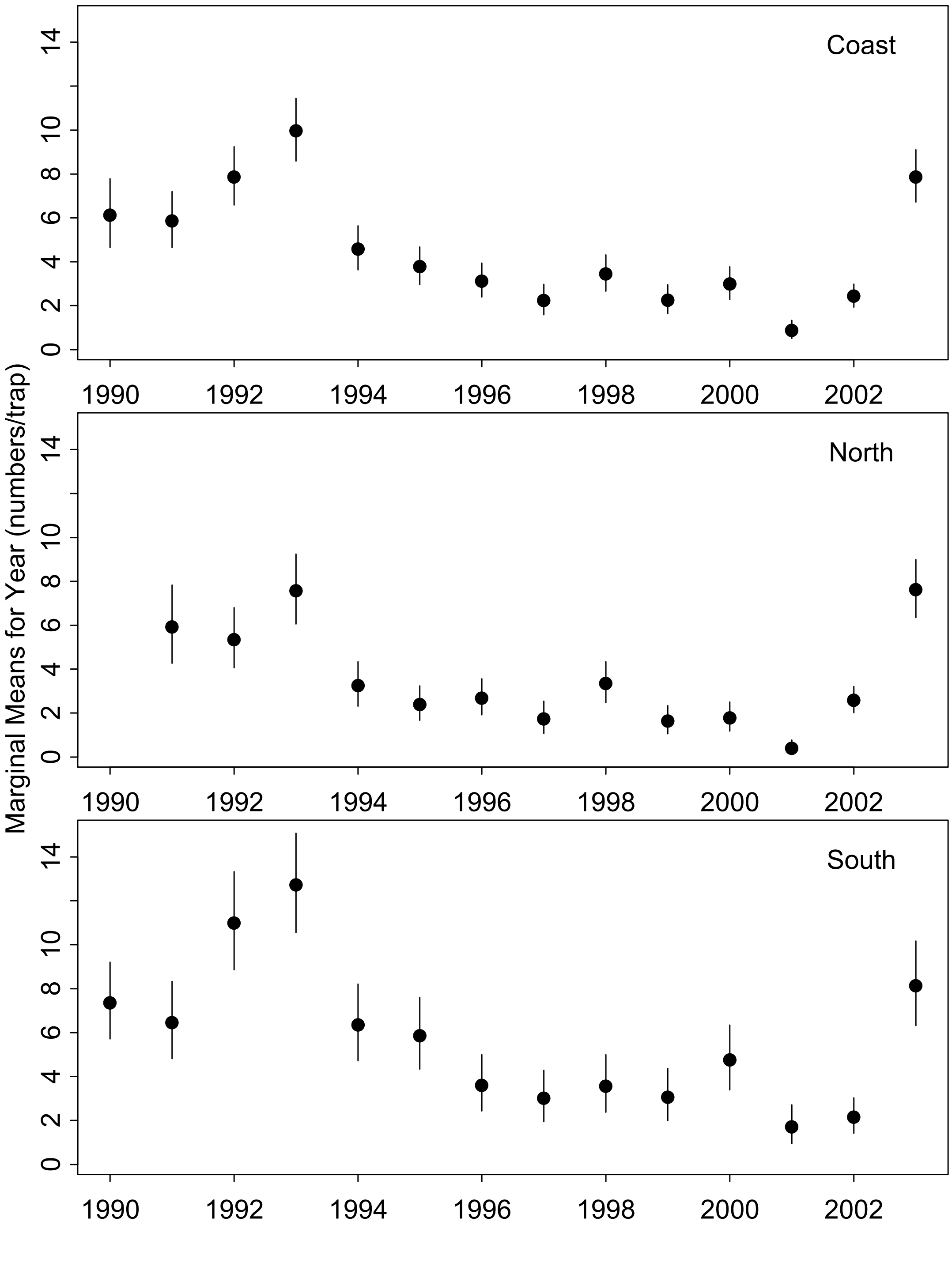


Figure J.7 Marginal mean estimates for the year factor by area. Vertical bars represent ± 2 standard errors.

APPENDIX K BIOMASS DYNAMICS MODEL

K.1 BIOMASS DYNAMICS MODEL K-1
K.2 MODEL DESCRIPTION K-1
K.3 MODEL DATA K-4
K.4 TWO-STOCK ANALYSIS K-4
K.5 MODEL RESULTS K-5
K.6 MODEL PROJECTIONS, PERFORMANCE INDICATORS, AND DECISION TABLES K-6
K.7 INTERPRETATION OF DECISION TABLES K-8
K.8 LITERATURE CITED K-9

K.1 Biomass dynamics model

For the 2002 stock assessment, a simple biomass dynamics model was introduced to integrate the sablefish abundance indices and to provide a pragmatic tool for projecting relative abundance and evaluating consequences of alternative annual total annual catch (TAC) levels (Kronlund et al. 2003). A major premise underpinning the 2002 model was that the biomass of B.C. sablefish vulnerable to trap fisheries had been low but relatively stable between 1996 and 2002. Consequently, a parameter representing the average sablefish production over that low and relatively stable period was estimated and that level of production used in a "pessimistic" stock projection scenario.

The concept of a relatively stable biomass of vulnerable sablefish in B.C. is clearly not appropriate this year, given the large increases observed in the 2003 standardized survey and northern fishery catch rates. Therefore, the biomass dynamics model was extended to estimate annual production parameters and thereby allow inter-annual variation in stock production. The production terms represent the net changes in biomass resulting from fish growth, recruitment, immigration, emigration, and changes in vulnerability to trap gear. The time span for the analysis is extended through the inclusion of a nominal catch rate (CPUE) abundance index. Ideally, the time series of the standardized CPUE index would have been extended through inclusion of pre-1990 tow-by-tow logbook data, however these data are not available.

The biomass dynamics model provides a vehicle for examining the consequences of alternate TAC decisions in a simple framework and is not intended to capture all the complexities of sablefish population dynamics. Like the 2002 analysis, the model is formulated as a Bayesian analysis, which allows the tagging-based abundance index to be treated as absolute index but with considerable uncertainty.

K.2 Model description

The biomass dynamics model simulates changes in vulnerable biomass as a function of the catch removed each year and annual productivity terms. For this analysis, productivity encompasses the net effect of changes to the *vulnerable* biomass due to recruitment, growth, immigration, emigration and changes in vulnerability to trap gear. In addition to catch, the data inputs include the four abundance indices derived from the nominal trap fishery catch rates, the standardized trap fishery catch rates, the standardized survey, and the tag-recovery model. Through inclusion of the nominal CPUE series the time span of the analysis extends back to 1979, a substantial improvement over last years' analysis that used data beginning in 1996 only. This series also incorporates a period of contrast in stock abundance, which is preferable to the general decline in stock indices used in the biomass dynamics model in 2003 (Kronlund et al. 2003). A single stock model is fit to the data because the tag-recovery index of trap vulnerable biomass is not separated into north and south area components.

A description of model parameters, data, and assumptions about prior distributions used in the biomass dynamics model is given in Table K.1. The following equations describe model dynamics for the vulnerable stock:

$$B_{1979}=\exp(\upsilon)$$

$$S_i = sB_i - \tilde{C}_i \qquad 1979 \geq i \leq 2003$$

$$B_{i+1} = S_i + P_{i+1} \qquad 1979 \geq i < 2003$$

$$s = \exp(-M)$$

where B_i is the vulnerable biomass at the beginning of year *i*, S_i is the vulnerable biomass in year *i* after catch and natural mortality have occurred, $\tilde{C}_i$ is the catch in year *i*, P_i is the production in year *i*, and *s* is the annual fraction of fish surviving natural mortality given the instantaneous natural mortality rate, *M*. To ensure a non-negative population, the production parameters (ψ_i) estimated through the model-fitting process are defined as

$$\psi_{i+1} = \ln\left(\frac{S_{i+1}}{S_i}\right) \quad .$$

Then, the production terms are given by

$$P_{i+1} = S_i\left(\frac{\exp(\psi_{i+1})}{s} - 1\right) + \frac{\tilde{C}_{i+1}}{s} \quad .$$

Note that ψ_{1980} is not estimated but is set equal to ψ_{1981}. This is done to reduce the number of parameters used to define the stock in the first few years of the analysis.

The predicted relative abundance indices $\left(\hat{I}_i^j\right)$ are estimated as

$$\hat{I}_i^j = q^j B_i \left(1 - t^j \left(1 - s\right)\right) - t^j \tilde{C}_i \quad ,$$

where the relative abundance series are indexed by superscript j and t^j is the fraction of the year prior to j^{th} index measurement.

A Bayesian approach was used to estimate model parameters (Gelman et al. 1995). Bayesian estimation allows the absolute estimates of vulnerable biomass from the tagging-based analysis to be used, while recognizing the considerable uncertainty in these estimates. The objective function is defined as a negative log-posterior

$$\text{Objective } (\mathbf{p}) = -\sum_j \sum_i \log\left[L\left(\mathbf{p} \mid \tilde{I}_i^j\right)\right] - \log\left[\pi\left(\mathbf{p}\right)\right] \quad ,$$

where $L\left(\mathbf{p} \mid \tilde{I}_i^j\right)$ is the likelihood of data observations $\tilde{I}_i^j$ given parameter vector **p,** and π is the joint prior density of the parameter vector **p**. A normal distribution was assumed for the logarithm of the abundance indices. The negative log-likelihood for the abundance index data is then

$$-\log\left[L\left(\mathbf{p} \mid \tilde{I}_i^j\right)\right] = \sum_{j=1}^{4} \sum_{i=J_j}^{i=K_j} \log\left(\sigma_i^j\right) + 0.5\left(\frac{\log\left(\tilde{I}_i^j / \hat{I}_i^j\right)}{\sigma_i^j}\right)^2 \quad ,$$

where J_j and K_j are the first and last years where abundance index j data are fit, respectively. Uninformative priors (ie. unbounded uniform distributions) were assumed for most model parameters (see Table K.1 for details). The exceptions were:

1. a uniform prior for the natural mortality parameter, M, over the range 0.06 to 0.1;
2. a normal prior for the tagging-based proportionality constant, q^1, with mean 1 and variance $\sigma_{q^1}^2$.

The negative logarithm of the joint prior density of the model parameters is then

$$-\log\left(\pi\left(\mathbf{p}\right)\right) = 0.5\left(\frac{q^1 - 1}{\sigma_{q^1}}\right)^2 \quad .$$

We treat the abundance index proportionality parameters $\left(q^j\right)$ that have uniform priors as nuisance parameters. Bull et al. (2003) derived the analytical solution for these parameters:

$$q^j = \exp\left(\frac{\sum_{i=J_j}^{i=K_j} \left(\left(\ln\left(\tilde{I}_i^j\right) - \ln\left(\hat{I}_i^j\right) \right) / \sigma_i^j \right)}{\sum_{i=J_j}^{i=K_j} 1/\sigma_i^j} \right) \qquad 2 \le j \le 4 \quad .$$

The model was implemented using the AD Model Builder software package (Otter Research 2000). This software package uses a Markov Chain Monte Carlo (MCMC) method based on the Metropolis-Hastings algorithm (Gelman et al 1995) to obtain samples from the full posterior distribution. Ten million MCMC draws were done separately for each model run. A sample (n=2000) from the multivariate posterior distribution from each was stored and used in the projection simulations.

K.3 Model data

The primary data used in the biomass dynamics model are the annual catch and abundance indices (Table K.2). The total annual catch estimates were based on the coastwide totals for all fisheries and uses (Appendix E). Abundance indices fit in the model include: the tagging-based index (Appendix H); the sablefish standardized survey index (Appendix J); the standardized trap fishery CPUE index (Appendix F), and the nominal trap fishery CPUE index (Appendix E).

The logs of the abundance index data were assumed to be normally distributed. The tagging-based index points are the medians of the marginal posterior distributions (Case 1, Appendix H) and the variance assumed in the biomass dynamics model is calculated as the variance of the log of the marginal posterior estimates (Table K.2). For the survey and fishery standardized CPUE indices, the model estimates of the standard errors of the indices are based on sampling error only, whereas lack-of-fit in the biomass dynamics model is a result of both sampling and process error. For this reason we select *ad hoc* values of 0.3 for the standard deviations of these data. The nominal CPUE index series is included only to extend the analysis to an earlier starting year. The standardized fishery CPUE estimates should be superior to the nominal estimates because they theoretically account for changes in fishing patterns. For this reason, and to avoid using the same information twice, we do not want the nominal CPUE index to influence the model fits for years where both measures are available. However, we do need to have overlap in the two series so that the relative value between their q's can be estimated. For these reasons, we assume a standard deviation of 0.35 for years where we have only the nominal CPUE abundance index data and a value of 0.8 for years where there are more data available.

K.4 Two-stock analysis

During the 2002 sablefish stock assessment review, PSARC had requested that separate estimates of northern and southern B.C. sablefish be attempted through the biomass dynamics analysis for the 2003 assessment (Fargo 2003). In response, two alternate model formulations that provided separate northern and southern B.C. sablefish estimates were investigated. Results from both model formulations were unsatisfactory.

The first model that was investigated used the same formulation as described above, but was fit to either northern or southern B.C. data only. For these analyses the tagging-based abundance indices, which are estimated only on a coast-wide basis, were not fit in the biomass dynamics models. For both the northern and southern B.C. analyses the estimates of vulnerable biomass were unrealistically low, generally ranging between 2,000 and 3,000 t.

The second model that was investigated had a similar structure to that described above, but estimated both northern and southern stock and production estimates while fitting to separate northern and southern abundance indices for all data except the tagging-based estimates. The tagging-based indices were fit to the sum of the estimated northern and southern biomasses. While this model structure ensured reasonable biomass estimates for the combined northern and southern regions because an absolute abundance measure was being used, the biomass estimates for one of the regions was always low (again, in the range of 2,000 to 3,000 t). For some of the MCMC chains that were obtained with this model formulation, the region with the low biomass would change throughout the chain.

The conclusion of these efforts to estimate northern and southern B.C. biomass is that separate absolute abundance indices will be required to obtain acceptable results. Attempts to estimate separate northern and southern B.C. biomass through a tagging-based model should be investigated but could be problematic.

K.5 Model results

Figure K.1 shows the thinned posterior chains for the 2003 biomass and the tagging-based proportionality constant, q^1 from the MCMC algorithm. The chains for all estimated parameters are well mixed and the autocorrelations in the parameter estimates are low (all between –0.06 and 0.06), indicating good convergence to the posterior distribution. The marginal posterior distributions of the Pearson residuals ([observed-fitted]/[standard deviation]) for the model fits to the four index data series show the trade-offs in fitting to the different series (Figure K.2). That is, negative residuals for one index are balanced by positive residuals for another. The distributions of the standardized residuals for the 1981-1999 nominal CPUE series are approximately standard normal, which is expected given there is only one abundance series being fit over this period.

The marginal posterior distribution of the natural mortality parameter, M, is similar to its' prior distribution indicating there is little information in the data about this quantity (Figure K.3). The marginal posterior distribution of the tagging proportionality parameter, q^1, is shifted considerably to the right of its' prior distribution, suggesting there is information in the data about this parameter. The net result of this shift is that biomass estimates are lower than would have been obtained had there been higher coherence between the posterior and prior distributions.

Distributions of the vulnerable biomass estimates and of the stock production estimates are shown as quantile plots in Figure K.4. Over the period of the analysis, there appear to be two distinct production stanzas – the first up to 1993 and the second beginning in 1994. The 2003 production estimates may signal resumption of production levels similar to the pre-1994 period, however several more years of positive index values will be required to substantiate entry to a stanza of relatively high production.

K.6 Model projections, performance indicators, and decision tables

The biomass dynamics model was used to project vulnerable stock biomass trends into the future. Short-term (five year) projections were conducted for a range of potential future catch levels. Each of these simulated projections held the catch fixed over the projection period. Additionally, long-term (1000 years) projections were conducted for a "no catch" scenario. These runs provide estimates of the distribution of unfished vulnerable biomass, which are used in some performance measures.

Simulating future stock biomass requires estimates of future production. The biomass dynamics model parameterization of the production parameters, ψ_i, is convenient for estimation because it ensures a non-negative population. However, it is not reasonable to base stock projections on these parameters because that would imply that future biomass levels are independent of future catch levels. The alternative of basing future production on the P_i parameters is also not useful because that leads to negative biomasses, even with no catch being taken. This is because the P_i are independent of current abundance. We minimize this problem by fitting a linear model to the relationship of $\log\left(B_{i+1}\right)$ to $\log\left(S_i\right)$ and basing future production estimates on the parameters of that fit. Linear model fits are obtained for:

$$\ln\left(B_{k,i+1}\right) = a + b\ln\left(S_{k,i}\right) + \varepsilon_{k,i} \qquad \varepsilon_{k,i} \sim N\left[0,\sigma_P^2\right] \ ,$$

where *k* indexes the sample from the posterior distribution. Given the apparent change in the general level of production between 1993 and 1994, the above model is fit to different ranges of years with the intent of representing average (fit all years), good (fit 1980-1993 production), and poor (fit 1994-2002 production) production periods. Data points and linear model fits for the three production stanzas are shown in Figure K.5. The histograms of Pearson residuals indicate approximately standard normal distributions, as would be expected if the above model provided an adequate description of the random component of the process (Figure K.5). The possible exception to this is for the "good" production stanza fit where the residual distribution is not symmetric. The relationships between production and vulnerable biomass are shown in Figure K.6, where production becomes negative at a smaller end of year biomass for the poor stanza, and higher productions are achieved for the good and average stanzas. This figure illustrates how the model departs from a standard production formulation, where production is not permitted to assume negative values. Parameters estimates for the three production stanzas are given in the following table.

Production		**Parameters**		
stanza	years	a	b	σ_P
average	1980-2003	4.6694	0.5731	0.4264
good	1980-1993	5.6956	0.4876	0.4276
poor	1994-2002	4.5186	0.5663	0.3137

Future production is then simulated as

$$P_{i+1} = \exp\left(a + b\ln\left(S_i\right) + \gamma_i\right) - S_i \qquad \gamma_i \sim N\left[0, \sigma_P^2\right] \ ,$$

where the parameters, $a, b,$ and σ_P^2, depend on the production stanza being simulated.

Long-term (1000 year) simulations were conducted for each of the three production stanzas and for production switching between poor and good every 10 years and every 30 years. These simulations were conducted with no catch. Although not guaranteed by the production formulation, the populations did not become negative for these simulations. The following table shows selected quantiles of the distribution of stock biomass (B_i) that were obtained from these simulations.

	Mean of xxth quantile of B_i		
Production stanza	**5th**	**50th**	**95th**
average	21552	50523	119099
good	27929	62280	139585
poor	16175	30185	56554
switching every 10 years	19261	42547	111318
switching every 30 years	18712	42239	115708

Differences among production stanzas are similar for each of the quantiles listed. The poor production stanza is approximately half the good stanza in each case. The quantiles of stock biomass for the runs where the production stanzas switch every 10 years and where they switch every 30 years are very similar. Switching between higher and lower production periods appear to be most consistent with the data, although we have no basis for determining the appropriate periodicity of the changes. The long-term simulations suggest that, given production shifts with approximately equal duration of good and poor production, the stock biomass will fall below 19,000 t about 5 percent of the time when no fishing occurs. Given that biomass levels at and below 19,000 t are expected with some frequency (i.e., 1 year in every 20) without fisheries, the 5th percentile of the unfished biomass, $B^{0.05}$, should not lead to conservation concerns.

Thus, two performance measures based on the 5th percentile of the distribution of unfished trap vulnerable biomass, $B^{0.05}$=19,000 t were adopted.

For the 2002 sablefish stock assessment, the probability that the stock would increase from the current level was used as one of the performance measures. The rationale was that the stock was at a low level, and an increase in biomass was desirable for the fishery. For the current assessment the estimate of 2003 vulnerable stock biomass is close to historic high levels, so a performance measure that looks to increasing stock biomass is not appropriate. However, assessing whether future stock biomass remains above the 2002 estimates of vulnerable biomass was used as a basis to define two additional performance measures. Performance measures are summarized below:

1. the *probability* that vulnerable stock biomass is above $B^{0.05}$=19,000 t at the end of the projection period, $P\left(B_{2009} > B^{0.05}\right)$;
2. the *probability* that vulnerable stock biomass is above B_{2002} at the end of the projection period, $P\left(B_{2009} > B_{2002}\right)$;
3. the *magnitude* of the expected change in vulnerable stock biomass over the projection period, $E\left(B_{2009} / B^{0.05}\right)$;
4. the *magnitude* of the expected change in vulnerable stock biomass over the projection period, $E\left(B_{2009} / B_{2002}\right)$.

Decision tables that facilitate comparison of stock status at different future catch levels are used to present the probability of achieving the performance measures. The model constructs a distribution of B_{2003} over the sample from the MCMC chain. Thus, the full distribution of B_{2003} values can be used in decision tables to summarize results relative to current stock condition, i.e., the impacts of the B_{2003} being at the lower (or higher) end of the range of estimated values. This was achieved by dividing the marginal posterior distribution of 2003 vulnerable biomass estimates into three ranked groups (0th-25th, 25th-75th, and 75th-100th quantiles). Performance indicators are presented for each of these groups, representing expected outcomes given poor, medium, or good levels of biomass in 2003. Note that the group differences are relative. Also, note that we do not use the year-end biomass, S_{2003}, to construct the distribution of current biomass to avoid confusion by using both S_i and B_i terms in the decision tables.

K.7 Interpretation of decision tables

Short-term (5 year) stock projections are conducted with no catch and with catch levels ranging from 3,000 to 6,000 t, which encompasses the range of historic catches. All projections use the "average" stock productivity parameters. Decision tables that show the results relative to the alternate performance measures are presented in Table K.3. Model results are summarized in the following table for each performance measure.

Total Annual Catch 2004-2008	Performance Measure			
	$P(B_{2009} > B_{2002})$	$P(B_{2009} > B^{0.05})$	$E\left(B_{2009}/B_{2002}\right)$	$E\left(B_{2009}/B^{0.05}\right)$
0	0.94	0.97	2.83	3.07
3000	0.91	0.95	2.57	2.80
4000	0.89	0.93	2.48	2.70
5000	0.87	0.92	2.37	2.59
6000	0.83	0.89	2.26	2.46

These results are selected from Table K.3 by focusing on the expectation over the joint posterior which integrated results at low, average, and high categorizations of the 2003 biomass estimates.

The probability that vulnerable stock biomass remains above the 2002 biomass level is high, even at the 6,000 t future catch scenario (probability of 0.83). The probabilities that the biomass remains above the $B^{0.05}$ threshold are even higher, with a 0.89 probability given a 5-year catch level of 6,000 t. These simulations suggest that there is no reason for stock conservation concerns in the short-term. If stock production is lower than average over the next 5 years, then the probabilities of vulnerable biomass falling below $B^{0.05}$ will increase.

K.8 Literature Cited

Bull, B., Francis, R.I.C.C., Dunn, A., McKenzie, A., Gilbert, D.J., and M.H. Smith. 2003. CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.01-2003/08/01. NIWA Technical Report 124. 223 p.

Fargo, J. 2003. Proceedings of the PSARC Groundfish Subcommittee Meeting, January 14-15, 2003. Can. Sci. Adv. Sec. Proc. Ser. 2003/002.

Gelman, A.B., J.S. Carlin, H.S. Stern, D.B. Rubin. 1995. Bayesian data analysis. Chapman and Hall. London. 526 p.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

Otter Research Limited. 2000. An introduction to AD model builder, version 4: For use in nonlinear modeling and statistics. Otter Research Limited. Sydney, B.C. Canada. 127 p.

Table K.1 Description of model parameters, prior assumptions, and data for the biomass dynamics model.

Fundamental Model Parameters (estimated through minimization):

Parameter	Description	Prior
υ	The log of vulnerable biomass in the first year of the analysis (1979)	$\ln(\upsilon) \sim U[-\infty,\infty]$
ψ_i	Stock production parameters for years $1981 \le i \le 2003$	$\psi_i \sim U[-\infty,\infty]$
M	Instantaneous natural mortality rate	$M \sim U[0.06, 0.1]$
q^1	Proportionality constant for the tagging-based abundance index	$q^1 \sim N\left[1,\sigma^2_{q^1}\right]$

Fixed model parameters:

Parameter	Description
$t^1 = 0.0$	Fraction of calendar year that occurs prior to tagging-based index observation
$t^2 = 0.875$	Fraction of calendar year that occurs prior to survey index observation
$t^3 = t^4 = 0.5$	Fraction of calendar year that occurs prior to commercial fishery index observation
$\sigma_{q^1} = 0.2$	Standard deviation of the tagging-based index proportionality constant.
σ_i^j	Standard deviation of the random error in abundance index j for year i

Model Parameters estimated as functions of fundamental parameters:

Parameter	Description
S_i	Vulnerable stock biomass in year i after fishery and natural mortality
B_i	Vulnerable stock biomass in beginning of year i
P_i	Stock production in year i
$\hat{I}_i^j$	Predicted abundance index for index j in year i
q^2,q^3,q^4	Proportionality constants for the survey-based and commercial fishery-based abundance indices. Estimated analytically based on prior distributions: $q^2,q^3,q^4 \sim U[0,\infty]$

Model data:

Data	Description
$\tilde{C}_i$	Observed catch (tonnes), in year i
$\tilde{I}_i^j$	Observed abundance index for index j in year i

Table K.2 Data used in the biomass dynamics model.

Year	Catch (t)	Tagging-based		Survey-based		Standardized CPUE		Nominal CPUE	
		Index	St.Dev.	Index	St.Dev.	Index	St.Dev.	Index	St.Dev.
1979	4387.0							16.920	0.35
1980	3794.7							15.422	0.35
1981	3830.2							14.508	0.35
1982	4027.7							16.845	0.35
1983	4346.5							16.446	0.35
1984	3827.4							12.918	0.35
1985	4192.7							17.327	0.35
1986	4448.8							15.596	0.35
1987	4630.5							15.089	0.35
1988	5402.6							24.736	0.35
1989	5324.0							25.673	0.35
1990	4904.9			4.880	0.3	9.047	0.3	20.973	0.80
1991	5112.4			4.646	0.3	10.941	0.3	26.043	0.80
1992	5007.5	97324	0.532	6.446	0.3	10.663	0.3	24.058	0.80
1993	5109.8	125042	0.288	8.365	0.3	9.395	0.3	20.980	0.80
1994	5001.5	92865	0.264	3.519	0.3	8.120	0.3	18.964	0.80
1995	4178.8	59597	0.254	2.815	0.3	6.403	0.3	15.037	0.80
1996	3470.5	55930	0.244	2.260	0.3	6.006	0.3	14.928	0.80
1997	4142.1	40671	0.256	1.511	0.3	5.263	0.3	13.317	0.80
1998	4591.7	35868	0.223	2.529	0.3	4.845	0.3	13.388	0.80
1999	4717.6	24292	0.250	1.526	0.3	5.015	0.3	13.705	0.80
2000	3833.5	25501	0.195	2.142	0.3	4.573	0.3	12.326	0.80
2001	3215.4	14690	0.223	0.449	0.3	3.856	0.3	9.932	0.80
2002	2786.9	16219	0.314	1.679	0.3	3.935	0.3	9.755	0.80
2003	1900.0			6.448	0.3	6.972	0.3		

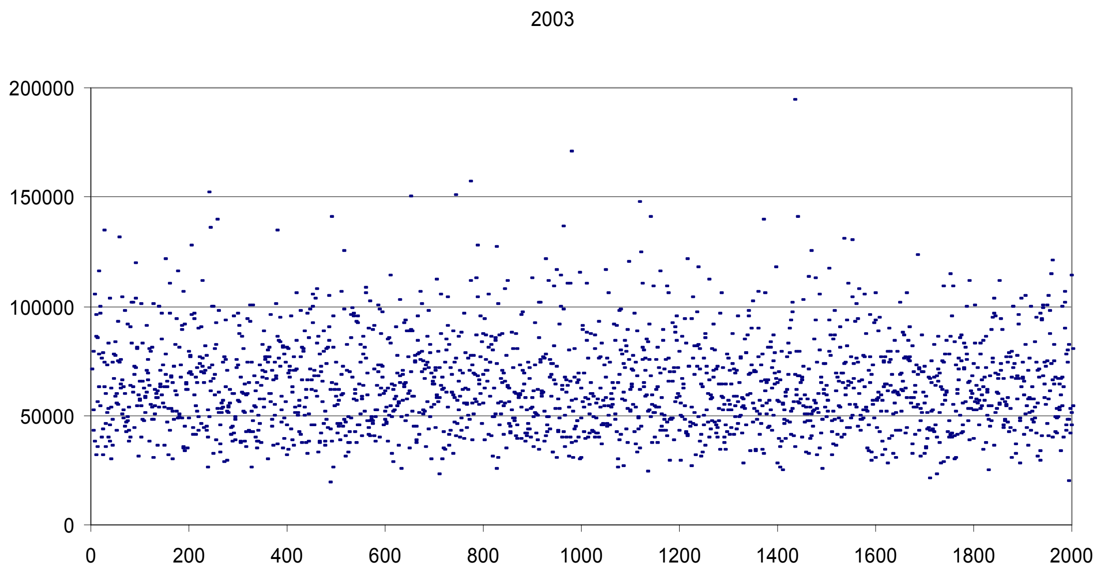
Table K.3 Decision tables showing the values for four performance measures for projections at a range of future catch levels. Results are presented relative to current (2003) vulnerable biomass, and the "expectation" integrates over the range of current biomass levels.

Total Annual Catch 2004-2008	$P(B_{2009} > B_{2002})$			
	Current Biomass			
	Low	Average	High	Expectation
0	0.98	0.95	0.89	0.94
3000	0.95	0.92	0.85	0.91
4000	0.93	0.90	0.83	0.89
5000	0.91	0.88	0.80	0.87
6000	0.87	0.85	0.77	0.83

Total Annual Catch 2004-2008	$P(B_{2009} > B^{0.05})$			
	Current Biomass			
	Low	Average	High	Expectation
0	0.97	0.98	0.97	0.97
3000	0.94	0.95	0.96	0.95
4000	0.93	0.93	0.94	0.93
5000	0.90	0.92	0.93	0.92
6000	0.87	0.89	0.91	0.89

Total Annual Catch 2004-2008	$E\left(B_{2009}/B_{2002}\right)$			
	Current Biomass			
	Low	Average	High	Expectation
0	3.35	2.81	2.33	2.83
3000	3.03	2.56	2.14	2.57
4000	2.91	2.47	2.06	2.48
5000	2.77	2.37	1.99	2.37
6000	2.62	2.26	1.90	2.26

Total Annual Catch 2004-2008	$E\left(B_{2009}/B^{0.05}\right)$			
	Current Biomass			
	Low	Average	High	Expectation
0	2.96	3.08	3.15	3.07
3000	2.68	2.81	2.89	2.80
4000	2.57	2.71	2.80	2.70
5000	2.45	2.60	2.69	2.59
6000	2.32	2.47	2.58	2.46



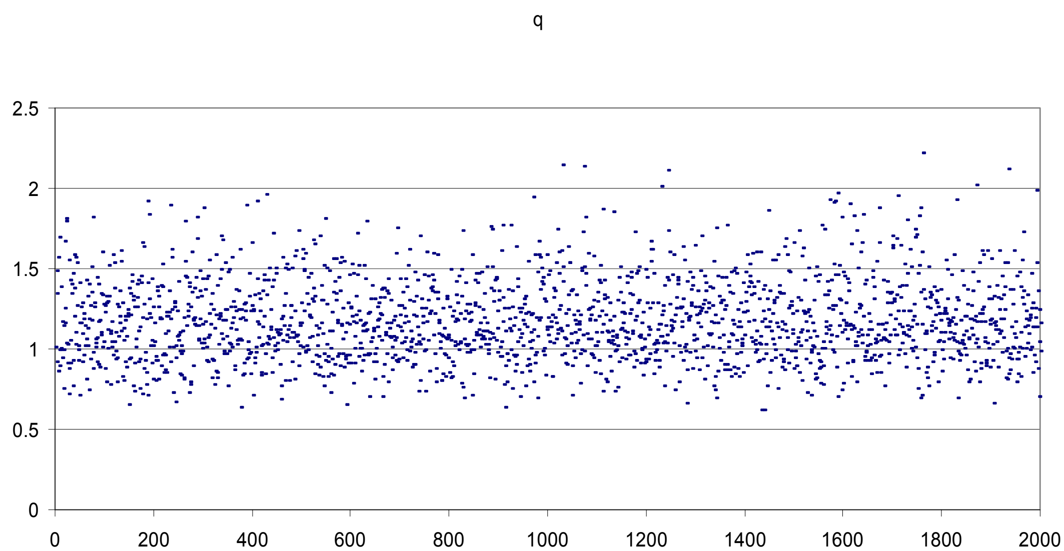


Figure K.1 The thinned MCMC chains for the 2003 biomass (t, upper panel) and the tagging-based index "q" parameter (lower panel).

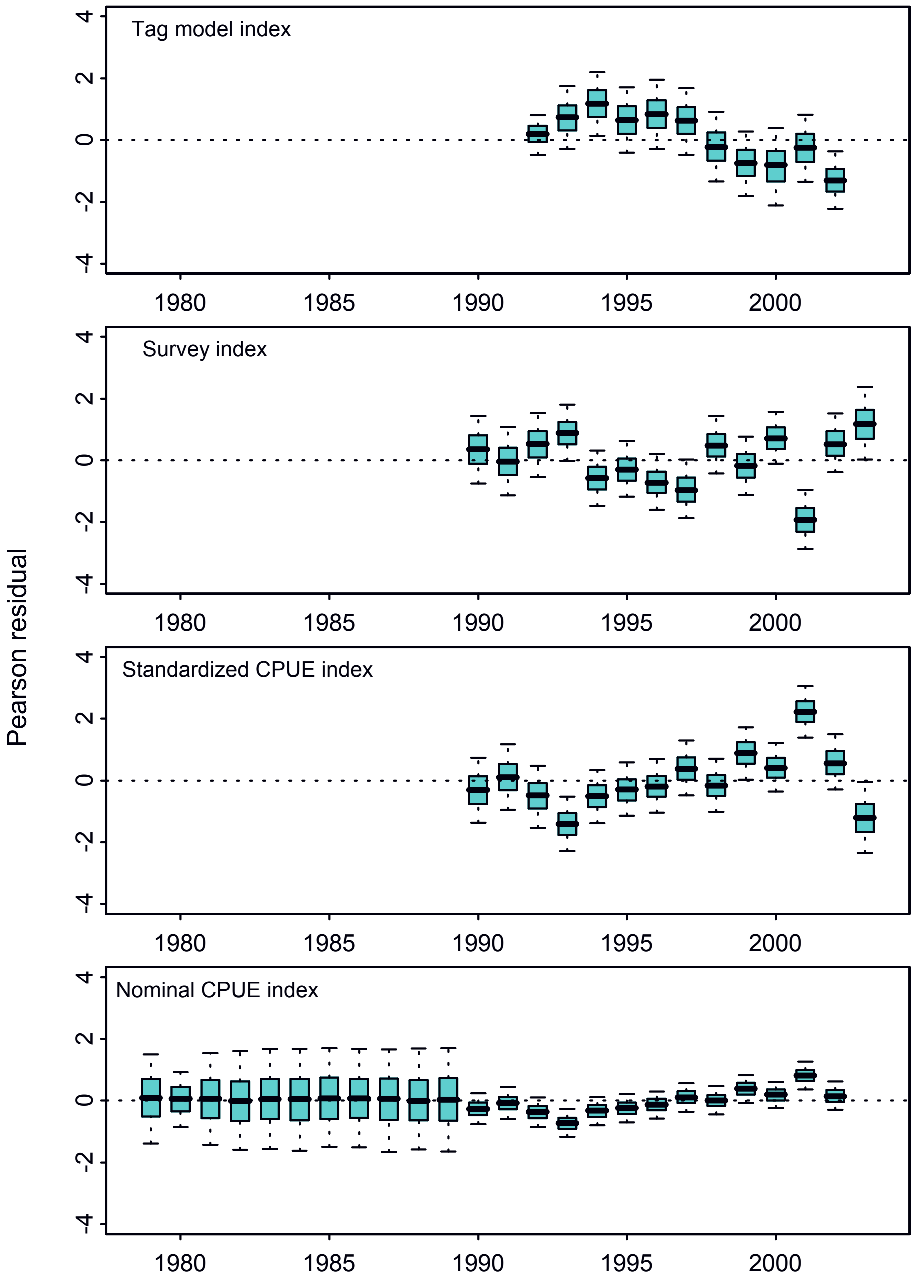


Figure K.2 Quantile plots of the marginal posterior distributions of Pearson residuals for model fits to the annual abundance data series. The annual median is shown by heavy horizontal lines, the interquartile range by the shaded boxes, and the 5th and 95th quantiles by the 'whiskers'.

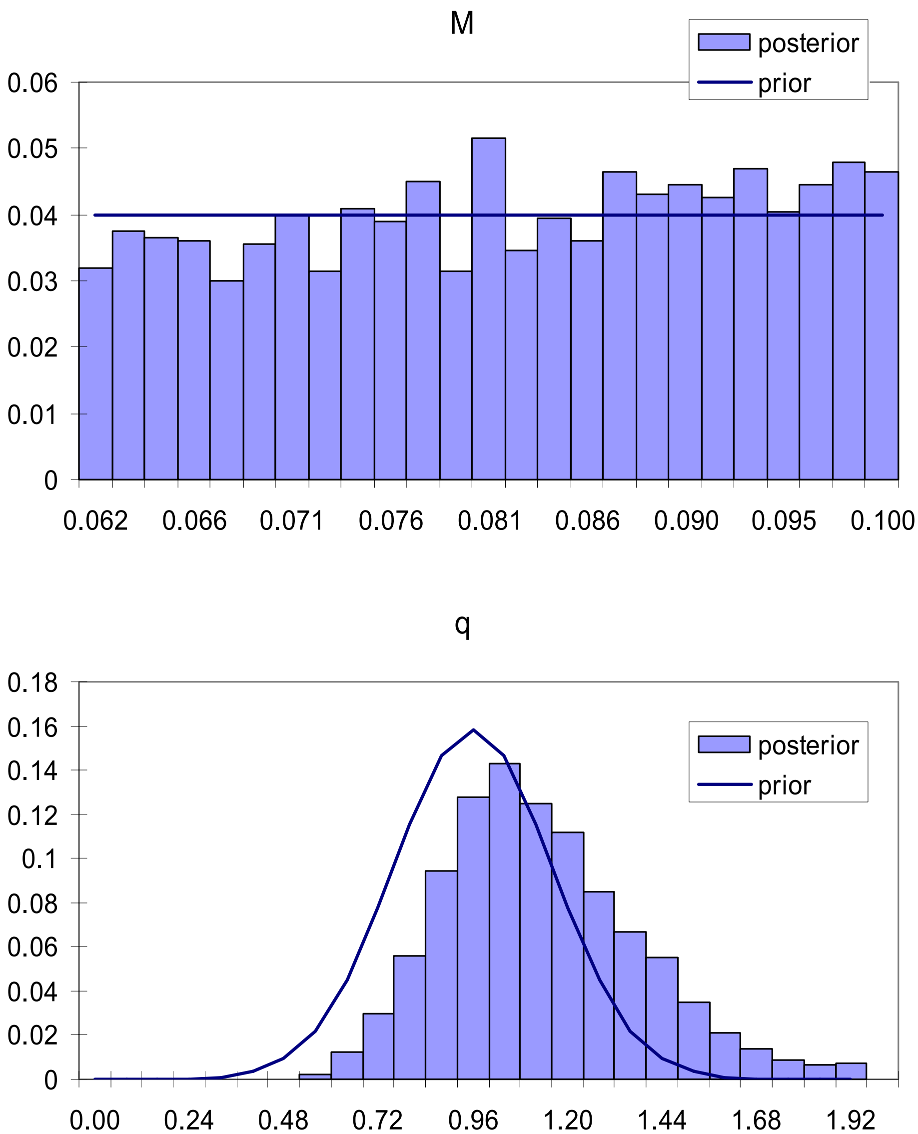


Figure K.3 Prior and marginal posterior distributions for biomass dynamics model parameters *M* and q^1.

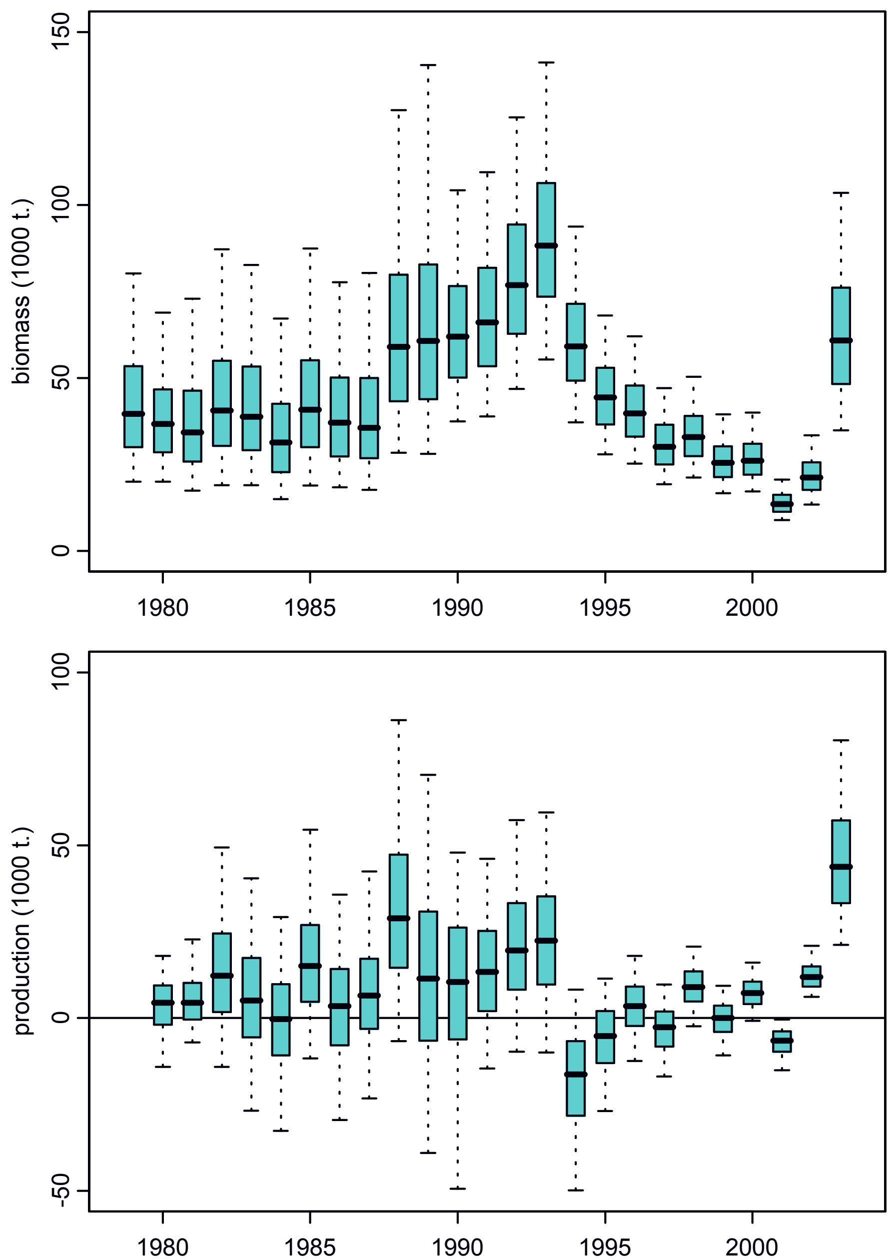


Figure K.4 Quantile plots of the annual marginal posterior distributions for vulnerable biomass (t, upper panel) and stock production (t, lower panel). The annual median is shown by heavy horizontal lines, the interquartile range by the shaded boxes, and the 5th and 95th quantiles by the 'whiskers'.

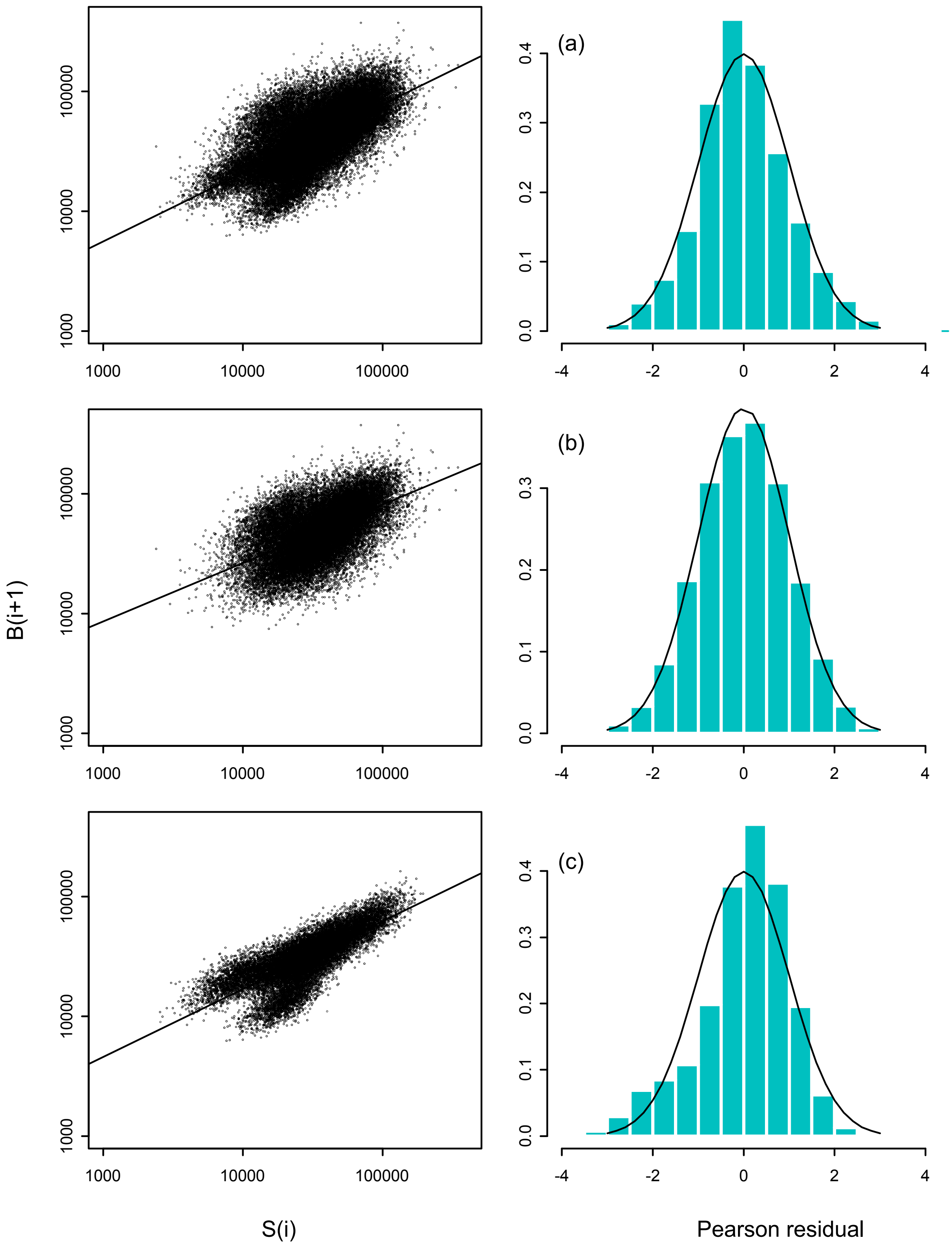


Figure K.5 Linear model fit of log(B[i+1]) and log(S[i]) for the 3 production stanzas (a: 1980-2003; b: 1980-1993, c:1994-2002), shown in the panels on the left, and the Pearson residuals from the fit shown in the panels on the right.

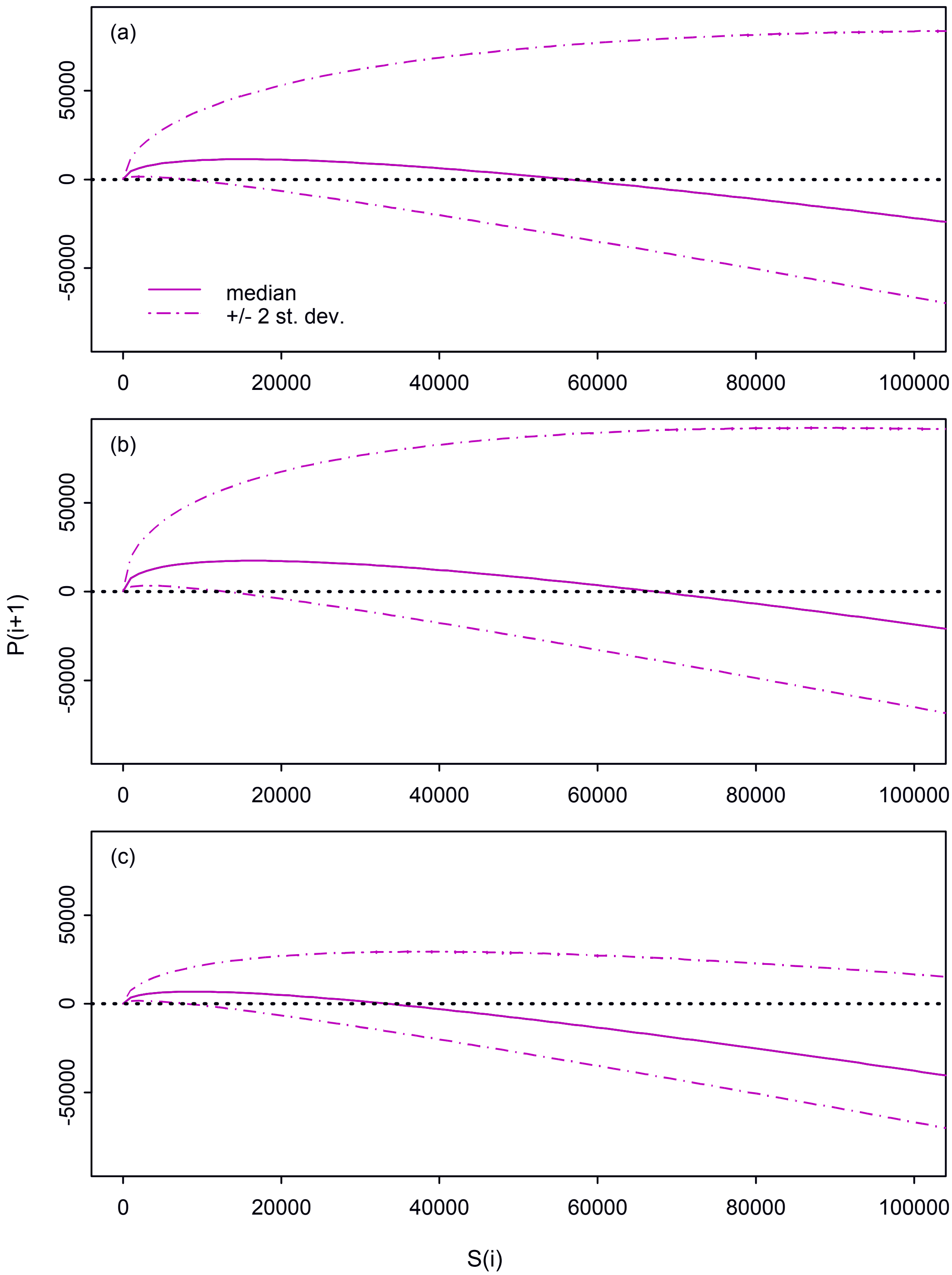


Figure K.6 Predicted production (P[i+1]) as a function of year-end biomass (S[i]) for the 3 production stanzas (a: 1980-2003; b: 1980-1993, c:1994-2002). For reference, a dotted line is shown at the 0 value for production.

APPENDIX L SABLEFISH IN NON-DIRECTED SURVEYS

L.1 IPHC STANDARDIZED STOCK ASSESSMENT SURVEY L-1
Background *L-1*
Catch rates *L-2*
Biological data *L-3*
Potential of the IPHC survey for sablefish *L-3*
L.2 SHRIMP SURVEYS L-4
Background *L-4*
Catch and catch rates *L-5*
Biological data *L-5*
L.3 LONGSPINE THORNYHEAD SURVEY L-6
Background *L-6*
Biomass estimates *L-7*
Comparison of thornyhead survey with sablefish indexing survey *L-7*
Potential of the thornyhead survey for indexing sablefish abundance *L-8*
L.4 LITERATURE CITED L-8

L.1 IPHC Standardized Stock Assessment survey

Background

The International Pacific Halibut Commission (IPHC) has conducted a fixed-station Standardized Stock Assessment (SSA) survey since 1993 to assess Pacific halibut (*Hippoglossus stenolepis*) in B.C. waters. Survey longline gear is designed to capture Pacific halibut, but also intercepts sablefish as a significant bycatch species. The collection of species composition data by the IPHC prior to 1993 was sporadic and often for selected species only. Thus, the analysis presented here is restricted to data collected from 1993 to 2003 when species composition data were regularly collected. Documentation of the SSA surveys since 1993 can be found in the IPHC Report of Assessment and Research Activities 1993 to 2002 (eg. IPHC 2000). The IPHC maintains experimental, tagging and survey data in a Microsoft Access database at the Commission offices in Seattle, Washington (http://www.iphc.washington.edu/halcom).

The survey protocol was a fixed station scheme; however, various changes have occurred in the choice and relative positioning of stations as described in annual IPHC Report on Assessment and Research Activities documents. To summarize, from 1993 to 1997 stations were grouped in triangular clusters with stations at the triangle vertices and a station centered in the triangle. Each cluster was sized to fit within a square of 10 to 12 nm depending on the year. Clusters of stations were positioned approximately 12 nm apart along a regular grid. Beginning in 1998, the survey design was based on a 10 nm square grid, with stations positioned at the vertices of the grid.

The longline fishing gear usually consisted of 5 to 8 skates of about 100 hooks each (IPHC 1999, 2000). Hooks were fixed, with 18 ft (5.5 m) spacing so that each skate was 1,800 ft (548 m) long. Size 16/0 circle hooks have been used from 1993 to 2003. In practice, the number of hooks varied slightly on each skate, and there may be small variation in the number of skates set within a survey year. Soak time was a minimum of 5 hours and was not permitted to exceed 24 hours. At each survey station, the gear was set in a predetermined direction (IPHC 1999) regardless of the prevailing bathymetry; there was no attempt to maintain a target depth along the set.

All Pacific halibut were enumerated at gear retrieval. For other species, the composition of the catch was generally determined by inspecting 20 hooks at, or near, the beginning of each skate as the gear was retrieved. Thus, total catch numbers per skate must be estimated for species other than Pacific halibut. However, in some years (1993-1996, 2003) survey technicians completely enumerated all species.

Data used in the analysis were restricted to those survey sets that had a purpose code corresponding to SSA survey data and were deemed to be "effective" sets by IPHC staff. Secondary species, those species that attacked an animal already hooked, were not considered since their occurrence was infrequent. Data quality control editing for 2003 has not been completed, so final results may differ from those presented here.

Catch rates

For years where complete enumeration of species was not conducted, the total catch by species was derived for each set by multiplying the species proportions observed on the skates actually inspected for species composition by the number of hooks, as described in Appendix I of Kronlund et al. (2003). The total number caught of a given species was obtained by summation over sets. There is no need to adjust the total by a sampling fraction due to sets, since all sets are inspected for bycatch. For this analysis, catch rates were calculated as numbers caught per IPHC "effective skate", as stored in the SSA database. The "effective skate" is defined as a skate of 100 circle-hooks with 18 foot (5.5 m) spacing. For gear that departs from the standard, an adjustment is applied to yield the number of "effective skates" (Sullivan et al. 1999). Although part of the adjustment incorporated into computing effective skates is specific to Pacific halibut, this adjustment was used to provide a common standard to correct for the numbers of hooks per skate and because adjustments specific to other species are not available. Summary statistics for catch rates were computed by forming the mean, median or other percentile of the catch rates per set over sets in the stratum of interest (e.g., year and area).

The impacts on catch rates due to annual changes in the distribution of fishing effort should be minimized by a survey design with (approximately) consistent spatial coverage. Figure L.1 shows sablefish catch rates portrayed as sized circles, where the area of the circle is proportional to the catch rate. Each circle corresponds to one set. Sets where the catch of sablefish was zero are indicated by plus symbols. Each figure panel shows a year of data and circles are scaled to the maximum catch rate across all years as indicated in the lower left corner of each panel. The survey area was partitioned into three *ad hoc* spatial strata: west coast Vancouver Island (sets south of 50.8°N), central B.C. (sets in Hecate Strait and Queen Charlotte Sound east of 131.5°W and north of 50.8°N), and Queen Charlotte Islands (sets west of 131.5°W and north of 50.8°N). Dotted horizontal and vertical lines on each panel indicate the *ad hoc* region boundaries.

Within the central Hecate Strait/Queen Charlotte Sound area, sablefish catch rates were higher in association with Moresby, Reed, and Sea Otter Troughs (Figure L.1). This feature becomes particularly striking in 1998 through 2003, but the visual impact is partly a function of the uniform survey grid adopted for those years. The spacing of the stations prior to 1998 meant that distances between station groupings were larger, thus, the continuity of catch rate patterns appears somewhat interrupted when compared to those observed in recent years. The figure suggests higher catch rates in 1998 and 1999 compared to other years for the central region, where sablefish catches were observed at a higher proportion of stations distributed over a wider area. Relatively high catch rates have been achieved at deep stations north of the Queen Charlotte Islands, with a peak again in 1998. Catch rates for sets along the west coast of Vancouver Island, where the time series is not as extensive, appear to have been greatest in 2001. Unfortunately biological data are not available to allow changes in size frequency to be assessed. Summary statistics of the catch rates for each region appear in Table L.1. A more thorough post-stratification analysis could lead to better choices of spatial and depth strata and the development of area weighted estimates of sampling error.

Biological data

Sablefish length frequency data are available from the 2003 survey only. These data are plotted in Figure L.2 for males and females. For 2003, the survey gear appeared to capture fish in the mid to high 40 cm size range and above. Few fish less than 45 cm were captured, even in the Hecate Strait region where commercial trawling intercepts age 1+ (approx. 30 to 40 cm) and 2+ juvenile fish (approx. 40 to 45 cm). Length frequency histograms show a mode at about 50 cm for both males and females in the Central region, and a second mode at 65 cm for males only. Females tended to represent animals greater than 80 cm in length in all regions. Mean fish size appeared not to change greatly with depth, but there were fewer small fish with increasing depth and there was an absence of fish greater than 60 cm fork length in samples from shallow depths in the central region.

Potential of the IPHC survey for sablefish

Results of this analysis warrant more detailed analysis and coordination of survey effort with the IPHC to work towards an index of sablefish abundance in the regions. Evaluation of the survey's ability to index sablefish depends on the collection of biological measurements over time; catch rates alone are inadequate since it is not clear what component of the population is being surveyed. Support for the use of longline surveys to index sablefish abundance can be found in the work of Sigler and Fujioka (1988) and Sigler (2000) for the Alaska stock. Note that age 1+ and 2+ juvenile fish may not be highly vulnerable to the longline gear used by the IPHC due to the hook size.

Nonetheless, one sample of fish from the IPHC survey off Vancouver Island included fish as small as 50 cm which lies in the 45 to 55 cm size range of sable fish intercepted by the shrimp trawl survey in 2003 (see below).

L.2 Shrimp surveys

Background

Systematic shrimp trawl surveys have been conducted in selected Pacific Fisheries Management Areas (PFMA) off the west coast of Vancouver Island (PFMA 123-125, see Sinclair et al. 2001 for more details) and in Queen Charlotte Sound (PFMA 107-111, Figure L.3). Sablefish were intercepted during these surveys. Spatial coverage has varied over time with annual surveys in PFMA 124 except for 1974, 1984, and 1986, and in PFMA 125 except for 1974, 1984, 1986, 1989, and 1991. The time series for PFMA 123 (Barkley Sound) extends from 1996 to 2003 but very few sablefish are caught and the data are not considered here. Surveys in Areas 107 to 111 date to the early 1960s, but only data from 1974 to 2003 are summarized here due to low sample size and variable spatial coverage prior to 1974. However, the number of sets conducted annually during the 1980s and early 1990s is very low in Queen Charlotte Sound.

The gear used from 1973 to 1976 consisted of a semi-balloon trawl fitted with a bobbin and roller groundline, fished with wood flat doors. The gear was changed in 1976 to a NMFS high-rising shrimp sampling trawl fished with steel Vee Doors (Boutillier et al. 1976). Comparative trials with both gear types were conducted at this time, but the change in efficiency due to adoption of the high-rising shrimp trawl has not been estimated for fin fish species. No attempt has been made to calibrate the historical data from 1973 to 1975 for gear effects. Fishing generally occurred at depths of 100 to 175 m in areas 124 and 125, and 125 to 225 m in areas 107 to 111. Tows were of 30 minutes duration unless curtailed due to hostile bottom or snags, and were conducted during daylight hours. The aggregate weight of sablefish caught per tow was recorded and counts of sablefish per tow have been noted beginning in 2001. No biological data for sablefish were collected (e.g., no length frequency data are available) until 2003 and only for the west coast Vancouver Island surveys.

In areas 124 and 125 survey stations were positioned along Loran lines (e.g., Y lines, 20 microseconds apart and Z lines, 10 microseconds apart). The inshore and offshore extensions of the survey were determined annually by occupying stations until shrimp catches became negligible or the bottom prohibited trawling. The Fisheries Research Vessels G.B. Reed (1973-1985) and W.E. Ricker (1987-present) were used for most surveys in areas 124 and 125. Charter vessels were used in 1977, 1978, and 1989 but no adjustments for vessel effects have been attempted for the data presented in this document. The timing of the survey has generally been during late April until late June, but in some years sets were conducted in the July to September period. The data analyzed here were restricted to sets conducted during April to June to reduce seasonal effects. Survey sets in areas 107 to 111 were arrayed as transects.

Catch and catch rates

Catch weight of sablefish per set over the time series in each survey area has generally been very low, with the equivalent of a few animals captured on each set (Table L.2). Areas 124 and 125 generally produced total catches per set of less than 200 kg, punctuated by relatively high catches in 1978, and 2001 to 2003. A similar pattern of relatively high catches occurred in areas 107 to 111 from 2000 to 2003.

Observed catch rates (kg/h) for each survey area and year are shown in Table L.2, and are plotted in Figure L.4 and Figure L.5 for the observed and log transformed scales, respectively. Mean catch rates from 2001 to 2003 increased more than tenfold over catch rates since 1979 in survey area 124 and 125, with the peak in 2002. The proportion of sets with zero sablefish catch decreased substantially during this period for areas 124 and 125 (Table L.2).

The spatial distribution of sets among years is shown in Figure L.6 for areas 124 and 125. Each panel of the figure shows sets with zero catch of sablefish as blue rectangles. Positive catch rates are shown as open circles, where the area of the circle is proportional to the observed catch rate (kg/h). Inspection of the annual patterns shows wide spatial occurrence of sablefish in 1978 that decreased by 1980 to incidental levels. Minor catches of sablefish occurred in some years (eg. 1992) until 2000 and 2001 when a very strong signal was observed throughout the survey zone. The catch rates were relatively high in 2003, but sablefish were encountered primarily in the southern range of the survey area. The time series of usable data for areas 107 to 111 is limited (Figure L.7) but there is some evidence of an increase in sablefish abundance from 2000 to 2001, that subsequently declines in 2002 and 2003.

Biological data

Individual sablefish weights are not available until 2003, and only for areas 124 and 125. However, a ratio estimate of mean fish weight can be computed for each set since 2001 by dividing the catch weight by the number caught. A 10 percent trimmed mean of these observations gave estimates of 387, 814 and 980 g in 2001 to 2003, respectively (Figure L.8). Individual fish measurements from three sets in 2003 resulted in mean length and weight estimates of 50 cm and 1208 g, respectively. Juvenile fish of about 400 grams have lengths of about 25 to 32 cm and correspond to age 1+, while fish of three or four years of age average about 45 to 50 cm (McFarlane and Beamish 1983, Rutecki and Varosi 1997). Thus the sizes of fish observed in 2001 likely reflect the 2000 year class. The survey results in 2001 and 2002 are consistent with observations from the continental U.S. Pacific coast where the 1999 and 2000 year classes are thought to be relatively strong (Schirripa 2002). A 10 percent trimmed mean of mean fish weight per set for areas 107 to 111 gave estimated fish weights of 605, 618 and 791 g in 2001 through 2003.

Two features of the shrimp survey data for sablefish should be noted when interpreting the results

1. Observed catches are small in most years, limited to only a few fish for each set;
2. The survey is restricted to 50 to 200 m in depth, which includes a small fraction of the depth distribution of sablefish so observed catch rates may be influenced by depth related movement as much as by stock abundance.

Accordingly, the catch densities on shrimp surveys are considered at this time to have potential as recruitment or juvenile abundance indicators, rather than as a stock abundance index. Biological measurements over time are required to determine year classes and allow comparison with other year class abundance estimates such as those available from U.S. triennial surveys (Schirripa 2002).

L.3 Longspine thornyhead survey

Background

In 2001 a three year bottom trawl survey funded by the Canadian Groundfish Research and Conservation Society was implemented on the continental slope of the west coast of Vancouver Island (Starr et al. 2002a). The survey used a stratified random design with three depth strata (501-800 m, 801-1200 m, 1201-1600 m) and, initially, six areal strata (Figure L.9). In 2002, an additional areal stratum was added to extend the northern range of the survey. Although the design of the survey is targeted at the longspine thornyhead (*Sebastolobus altivelis*) resource, the survey may provide informative abundance indices for other species such as sablefish. The objective of the analyses described here is to examine the utility of the thornyhead survey for indexing sablefish abundance on the west coast of Vancouver Island.

The first thornyhead survey was conducted between September 15 and October 2, 2001, using the F/V Viking Storm skippered by Chris Roberts and Kelly Anderson. The vessel for the 2002 and 2003 surveys was the F/V Ocean Selector with skipper Dave Clattenberg. The survey dates were September 7 to 23, 2002 and September 5 to 20, 2003. The thornyhead survey was conducted approximately 4 weeks earlier than the sablefish trap index survey. Detailed descriptions of the thornyhead survey design, gear specifications, and results from the 2001 survey are presented in Starr et al. 2002. Data quality control editing for the 2003 survey has not been completed, so final results may differ from those presented here.

Biomass estimates

Sablefish was the most abundant species caught in the thornyhead surveys, and few of the useable tows did not catch sablefish. Tows with no sablefish were generally in the deepest (1201-1600 m) strata.

Sablefish biomass estimates were derived using a standard survey design-based methodology that is described in Appendix D of Starr et al. (2002b). This approach scales the total catch in the area swept during tows in a stratum to the total area of that stratum. Calculations were based on the trawlable area, rather than total area, of the stratum. Starr et al. (2002a) present biomass estimates based on both the total distance traveled during a tow and the total distance with bottom contact during the tow. The bottom contact data is not yet available for 2003, so sablefish biomass estimates were calculated using the total distance approach. Also, in their analysis of the 2001 survey data, Starr et al. (2002a) combined tow data from regions "E" and "F" because of small sample sizes in region "F". We combined these two regions when analyzing all the data to ensure a consistent approach across years. Note that while estimates are presented as absolute biomass, they should be viewed as a relative index due to unknown survey catchability.

The estimated west coast Vancouver Island sablefish biomass declined from 2001 to 2002 and was back to the 2001 level in 2003 (Table L.3). The relative errors of the biomass estimates (standard error divided by estimate) are quite small, ranging from 0.13 to 0.16. Although not designed to index sablefish abundance, the thornyhead survey achieves a high degree of precision on the biomass estimates for this species. Note that the "total" sablefish biomass estimates do not include fish surveyed in region "G". This region was not surveyed in 2001 and by not including it in the 2002 and 2003 total biomass estimates, the annual values can be compared because they are based on the same survey areas.

Sablefish catch rates (kg/km^2) are generally highest in the shallow (501-800 m) depth strata, decreasing to very low catch rates in the deepest strata (1201-1600 m; Table L.3, Figure L.10). During the 2001 survey the highest sablefish catch rates occurred in the most southern region, "A", whereas in 2002 the highest catch rates occurred in the most northerly region, "G" (Figure L.10).

Comparison of thornyhead survey with sablefish indexing survey

Biological characteristics of sablefish caught in the thornyhead survey can be compared to those of sablefish caught in the sablefish trap indexing survey during the 2001 and 2002 surveys. Biological data from the 2003 sablefish trap index survey has not been processed. For these comparisons, the sablefish trap index survey data have been summarized using the same depth strata as used in the thornyhead surveys, and includes data from the Barkley Canyon, Esperanza, and Quatsino sablefish survey localities.

Selected quantiles of the length distributions, summarized by sex and depth strata, are shown in Figure L.11. The size distributions of sablefish captured by trawl gear in the thornyhead survey are similar to those of sablefish captured by trap gear in the sablefish survey, with perhaps a slight tendency to larger fish captured in the thornyhead survey. The size distribution of sablefish in the thornyhead surveys has been remarkably consistent between years.

The sex ratios of the sablefish caught in the thornyhead survey differ somewhat from those of sablefish caught in the sablefish survey (Table L.4). The thornyhead survey tends to capture a higher proportion of male sablefish, particularly in the shallowest depth strata. The apparent differences in sex ratios may result from differences in the timing of the two surveys (approximately 4 weeks) or differences in sablefish vulnerability to the gear.

Potential of the thornyhead survey for indexing sablefish abundance

The thornyhead survey appears to have very good potential for the development of a sablefish abundance index. Sablefish catch rates are relatively high, there are few tows with no sablefish catch, and the relative error of abundance estimates is small. A potential limitation of the survey for indexing sablefish abundance is that it does not cover the full sablefish distribution in shallower depths. Also, fishers have suggested that higher towing speeds would increase sablefish catch, but this may not limit the utility of the survey for developing relative abundance indices. Further investigations to explore the differences in sex ratios and possible depth-related differences in catch rates between trawl and trap gear, would be useful toward understanding the vulnerability of sablefish to different gear types. A sablefish trap survey, conducted at the same time as the thornyhead survey, would be one way to examine gear vulnerability differences.

L.4 Literature Cited

Boutillier, J.A., Yates, A.N., and Butler, T.N. 1976. G.B. Reed shrimp cruise 73-S-1, May 3-19, 1976. Fish. Mar. Ser. Data Rep. **13**: 46 p.

IPHC. 1999. Survey manual: standardized stock assessment survey 1999. Int. Pac. Halibut Comm. Version 99-02.

IPHC. 2000. Report of assessment and research activities 2000. Int. Pac. Halibut. Comm. Report.

Kronlund, A.R., V. Haist, M. Wyeth, and R. Hilborn. 2003. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: stock assessment for 2002 and advice to managers for 2003. Can. Sci. Adv. Sec. Res. Doc. 2003/071.

McFarlane, G.A. and R.J. Beamish. 1983. Preliminary observations on the juvenile biology of sablefish (*Anoplopoma fimbria*) in waters off the west coast of Canada. p. 119-136. *In* Proceedings of the Second Lowell Wakefield Fisheries Symposium, Anchorage, AK. Alaska Sea Grant Report 83-3.

Rutecki, T.L. and E.R. Varosi. 1997. Distribution, age, and growth of juvenile sablefish, *Anoplopoma fimbria*, in southeast Alaska. *In* Biology and management of sablefish, *Anoplopoma fimbria*. p. 45-54. NOAA Technical Report NMFS 130.

Schirripa, M.J. 2002. Status of the sablefish resource off the continental U.S. Pacific coast in 2002. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

Sigler, M.F. 2000. Abundance estimation and capture of sablefish (Anoplopoma fimbria) by longline gear. Can. J. Fish. Aquat. Sci. 57: 1270-1283.

Sigler, M.F. and J.T. Fujioka. 1988. Evaluation of variability in sablefish, *Anoplopoma fimbria*, abundance indices in the Gulf of Alaska using the bootstrap method. Fishery Bulletin, 86(3): 445-452.

Sinclair, A., S. Martell, and J. Boutillier. 2001. Assessment of Pacific cod off the west coast of Vancouver Island and in Hecate Strait, November 2001. Can. Sci. Adv. Res. Doc. 2001/159.

Starr, P. J., B. A. Krishka, and E. M. Choromanski. 2002a. Trawl survey for thornyhead biomass estimation off the west coast of Vancouver Island, September 15 to October 2, 2001. Can. Tech. Rep. Fish. Aquat. Sci. 2421: 60 p.

Starr, P.J., A.S. Sinclair, and J. Boutillier. 2002b. West coast Vancouver Island Pacific cod assessment: 2002. Can. Sci. Adv. Sec. Res. Doc. 2002/113. 29 p.

Sullivan, P.J., A.M. Parma and W.G. Clark. 1999. The Pacific halibut stock assessment of 1997. Int. Pac. Halibut Comm. Sci. Rpt. 79. 84 p.

Table L.1 Sablefish catch rates (number per effective skate) captured during the IPHC standardized stock assessment survey. The column p_0 is the proportion of stations with zero catch.

Region	Year	n	Min	1st. Quartile	Median	Mean	3rd Quartile	Max	p_0
Central	1993	81	0	0	0.67	4.24	7.01	21.73	0.40
Central	1995	86	0	0	0.30	4.42	7.60	25.21	0.43
Central	1996	92	0	0	0.21	4.37	5.23	31.69	0.47
Central	1997	95	0	0	0.00	3.69	6.94	18.11	0.53
Central	1998	109	0	0	2.43	5.52	9.60	29.52	0.36
Central	1999	112	0	0	1.21	4.26	6.48	23.85	0.38
Central	2000	108	0	0	0.69	3.00	4.65	27.98	0.44
Central	2001	113	0	0	0.00	3.09	3.25	34.18	0.58
Central	2002	113	0	0	0.00	2.49	4.03	22.99	0.51
Central	2003	114	0	0	0.56	2.58	3.43	21.92	0.36
QCI	1993	15	0	0	0.00	4.32	8.98	19.62	0.60
QCI	1995	20	0	0	0.00	6.85	11.72	25.55	0.55
QCI	1996	23	0	0	1.43	6.01	10.90	29.01	0.48
QCI	1997	22	0	0	0.00	5.92	11.55	29.64	0.55
QCI	1998	19	0	0	4.98	9.43	16.75	27.40	0.37
QCI	1999	19	0	0	3.71	7.51	10.33	29.70	0.37
QCI	2000	19	0	0	3.44	7.14	14.24	20.94	0.32
QCI	2001	19	0	0	4.38	8.45	13.04	28.02	0.37
QCI	2002	19	0	0	3.74	7.19	15.09	19.31	0.37
QCI	2003	19	0	0	3.36	6.04	11.77	16.48	0.37
WCVI	1999	36	0	0	0.00	3.06	5.11	18.32	0.58
WCVI	2001	37	0	0	0.99	8.20	13.67	47.86	0.46
WCVI	2002	37	0	0	0.00	4.38	6.04	23.67	0.51
WCVI	2003	36	0	0	0.00	3.07	2.67	27.27	0.53

Table L.2 Statistics for sablefish catch in shrimp surveys for areas 124 and 125. p_0 is the proportion of sets with no sablefish catch.

			Area	124						Area	125		
Year	Sets	Catch (kg)	Mean CPUE	Median CPUE	Maximum CPUE	p0	Year	Sets	Catch (kg)	Mean CPUE	Median CPUE	Maximum CPUE	p0
1975	64	51.75	1.62	0.5	18	0.47	1975	24	2.5	0.21	0	0.5	0.58
1976	70	3.25	0.09	0	4	0.91	1976	19	0	0	0	0	1
1977	55	10.5	0.38	0	4	0.84	1977	21	0	0	0	0	1
1978	85	625.25	14.83	4	144	0.2	1978	16	82	10.25	5	34	0.44
1979	52	246.25	9.52	7	54	0.23	1979	25	94	7.52	4	30	0.28
1980	59	37	1.25	0	18	0.61	1980	26	91	7	3	32	0.42
1981	58	110	3.85	2	30	0.24	1981	30	121	8.08	6	68	0.27
1982	57	20.5	0.72	0	4	0.65	1982	25	10.75	0.85	0	6	0.56
1983	51	42	1.66	0	20	0.71	1983	26	12	0.92	0	8	0.81
1984							1984						
1985	49	3	0.13	0	2	0.82	1985						
1986							1986						
1987							1987						
1988	71	68.75	2.44	0	53.33	0.58	1988	10	5.5	1.08	0.2	4	0.5
1989	67	21.75	0.64	0	20	0.87	1989						
1990	72	57.25	1.59	0	10	0.54	1990	10	1.25	0.25	0	2	0.8
1991	87	160.5	3.69	0	38	0.69	1991						
1992	77	201.5	5.26	0	96	0.61	1992	6	1	0.33	0	2	0.83
1993	70	87.75	2.8	0	57	0.61	1993	33	18.75	1.14	0	6	0.61
1994	67	65	2.13	0	18	0.52	1994	30	24.25	1.63	0	10.34	0.63
1995	63	117.75	3.76	0	112	0.68	1995	25	5.25	0.42	0	6	0.84
1996	57	113.5	3.97	2	27.1	0.3	1996	17	7.25	0.85	0	4	0.65
1997	63	87.3	2.77	1.4	13	0.37	1997	21	17.5	1.67	0	10.6	0.62
1998	46	31.7	1.47	0	16.4	0.61	1998	22	6.4	0.65	0	6.75	0.77
1999	52	82	3.15	1.8	28	0.29	1999	31	9	0.58	0	6.4	0.71
2000	45	121.8	5.84	2.71	39.6	0.27	2000	30	50.2	3.33	0.5	28	0.5
2001	51	1645.4	64.72	22.2	1781.6	0.04	2001	22	181.5	16.72	12.2	44.4	0.09
2002	51	2131.4	95.36	23	1890.6	0.14	2002	26	469.1	35.95	29	139.4	0.08
2003	47	618.42	27.52	7.8	301.2	0.23	2003	19	42.93	4.84	1.13	34.34	0.42

Table L.3 Summary of sablefish catch in the thornyhead survey by stratum for 2001, 2002, and 2003.

	Depth	2001 Survey			2002 Survey			2003 Survey			Stratum Area		Biomass Estimate		
Region	Stratum	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Total	Trawlable	2001	2002	2003
A	501-800	43.96	43.13	4	15.35	8.82	4	50.00	35.48	4	487	384	844.0	294.7	960.0
A	801-1200	14.45	5.99	4	5.04	2.74	4	6.36	4.77	4	702	637	460.4	160.5	202.6
A	1201-1600	3.77	4.10	2	0.55	0.78	2	4.68	3.13	2	577	577	108.7	15.9	134.9
B	501-800	34.06	25.93	4	12.08	2.75	4	11.03	5.84	4	330	233	396.8	140.7	128.5
B	801-1200	15.13	7.79	4	7.22	3.48	4	10.07	6.30	4	373	336	254.2	121.4	169.2
B	1201-1600	2.42	1.23	2	1.55	0.17	2	1.30	1.84	2	694	694	84.0	53.6	45.1
C	501-800	13.11	9.13	4	17.94	9.27	4	34.96	26.30	4	265	238	156.0	213.5	416.0
C	801-1200	9.65	3.34	4	4.42	2.85	4	5.29	3.74	4	380	380	183.4	84.0	100.5
C	1201-1600	1.27	0.13	2	0.15	0.21	2	0.00	0.00	2	462	462	29.4	3.5	0.0
D	501-800	37.86	30.49	4	9.66	5.11	4	76.87	49.99	4	274	154	291.5	74.4	591.9
D	801-1200	16.42	8.44	4	7.78	3.10	5	10.47	10.44	4	386	221	181.4	86.0	115.7
D	1201-1600	0.62	0.88	2	2.68	0.95	2	0.00	0.00	2	448	427	13.3	57.2	0.0
E+F	501-800	17.30	16.68	8	35.95	52.27	8	9.57	5.58	9	628	403	348.6	724.3	192.9
E+F	801-1200	11.65	6.33	8	16.58	11.32	8	22.36	24.67	8	895	657	382.7	544.6	734.4
E+F	1201-1600	2.30	0.14	2	0.51	1.01	4	1.05	1.32	4	830	775	89.1	19.6	40.5
G	501-800				39.78	23.03	2	26.07	4.22	2					
G	801-1200				20.69	5.32	2	30.60	22.39	2					
G	1201-1600				1.33	0.91	2	0.00	0.00	2					
Total				58			67				7731	6578	3823	2594	3832
R.E.													0.13	0.16	0.14

Table L.4 Comparison of sablefish sex ratio (proportion males) by survey, depth stratum and year.

		Thornyhead survey		Sablefish survey	
Year	Depth stratum	No. sexed	Prop. male	No. sexed	Prop. male
2001	501-800	1605	0.85	147	0.69
2002	501-800	848	0.82	625	0.73
2003	501-800	1254	0.78		
2001	801-1200	744	0.61	315	0.53
2002	801-1200	573	0.65	1078	0.62
2003	801-1200	624	0.81		
2001	1201-1600	26	0.23	189	0.03
2002	1201-1600	14	0.07	294	0.09
2003	1201-1600	21	0.14		

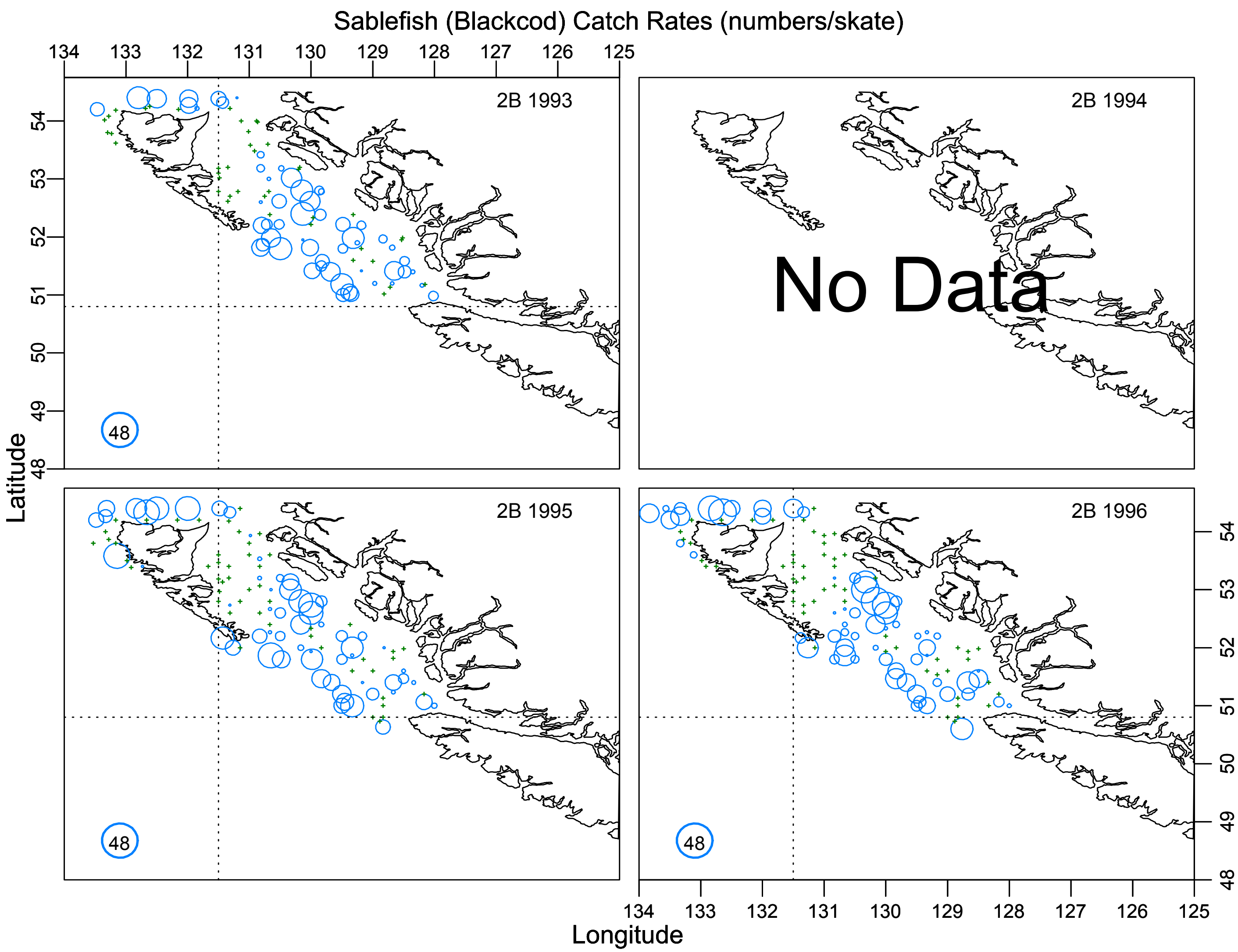


Figure L.1 IPHC SSA survey catch rates (num/effective skate) by year for sablefish. Zero catches indicated by “+” signs.

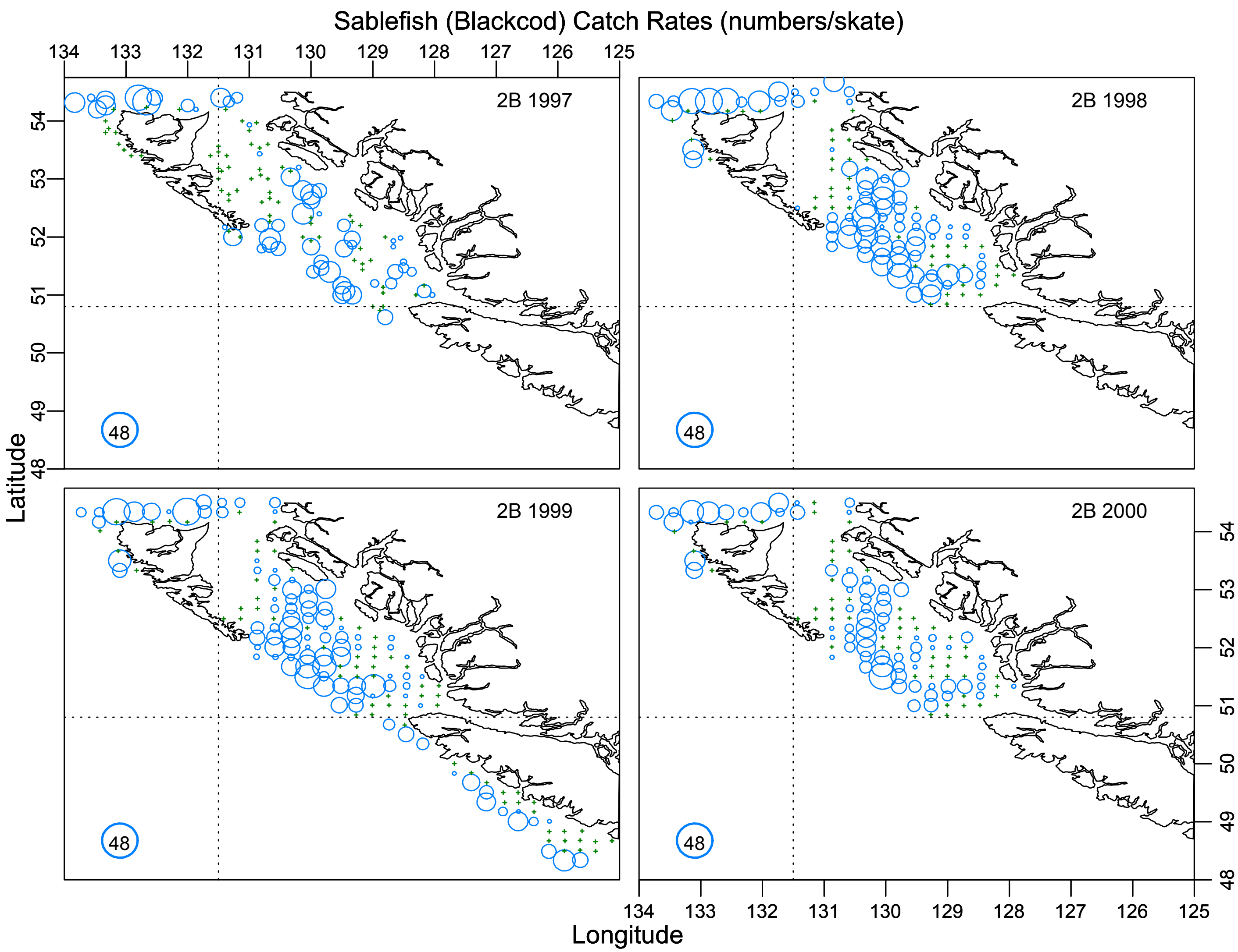


Figure L.1 Continued.

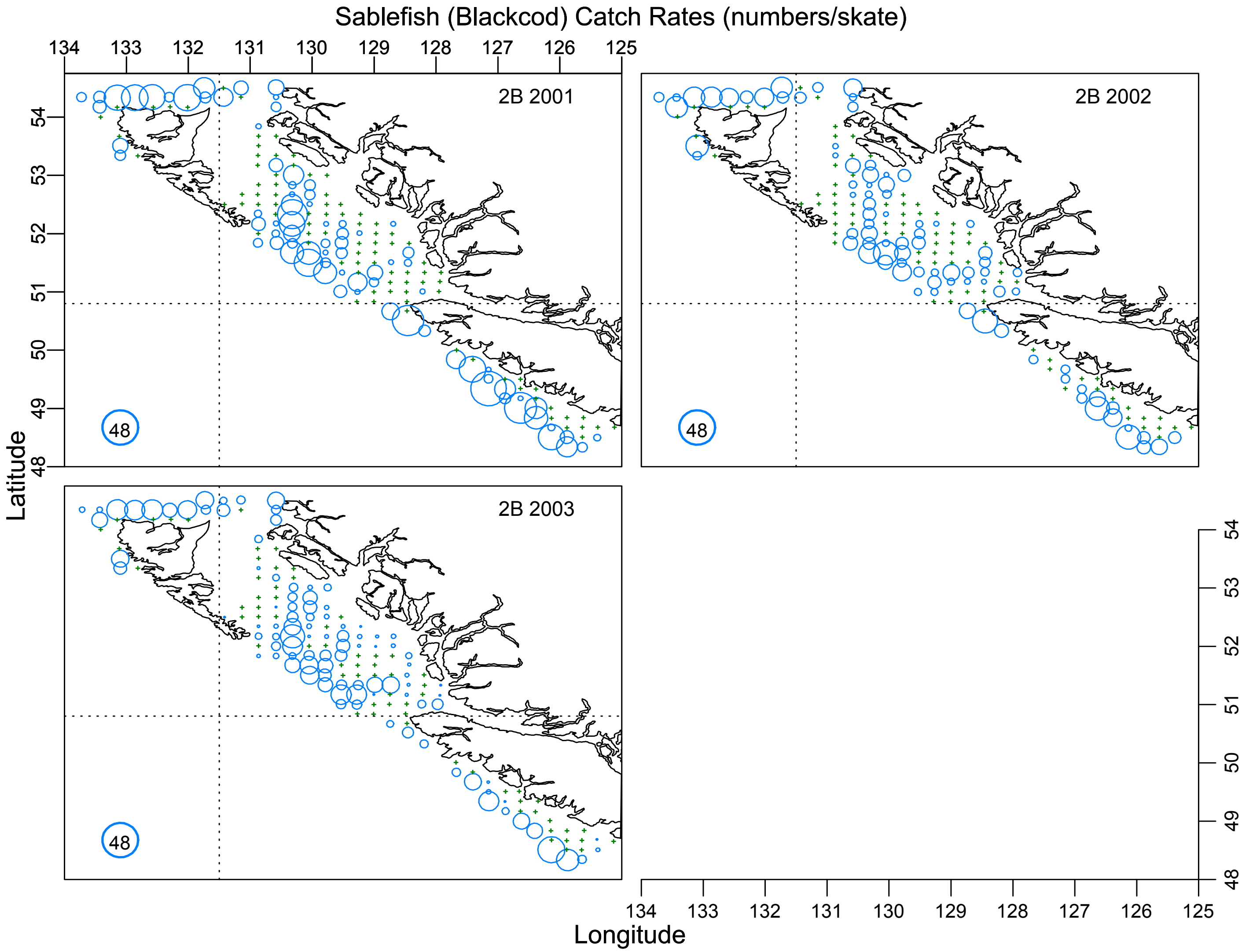


Figure L.1 Continued.

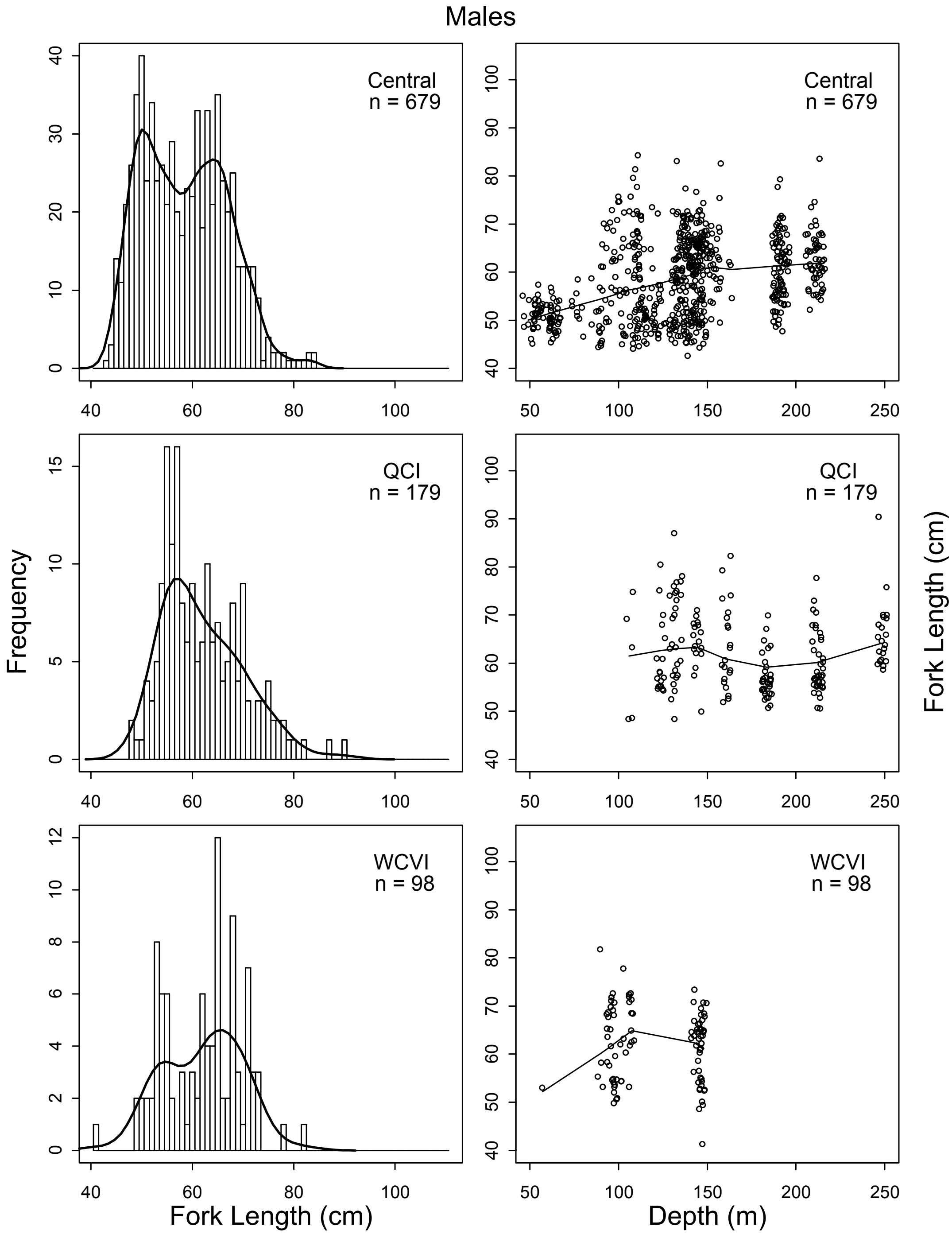


Figure L.2 Length frequency (left panels) and length at depth (right panels) of sablefish caught during the 2003 IPHC survey for three regions. The solid lines in the right panels are a smoothed trend lines.

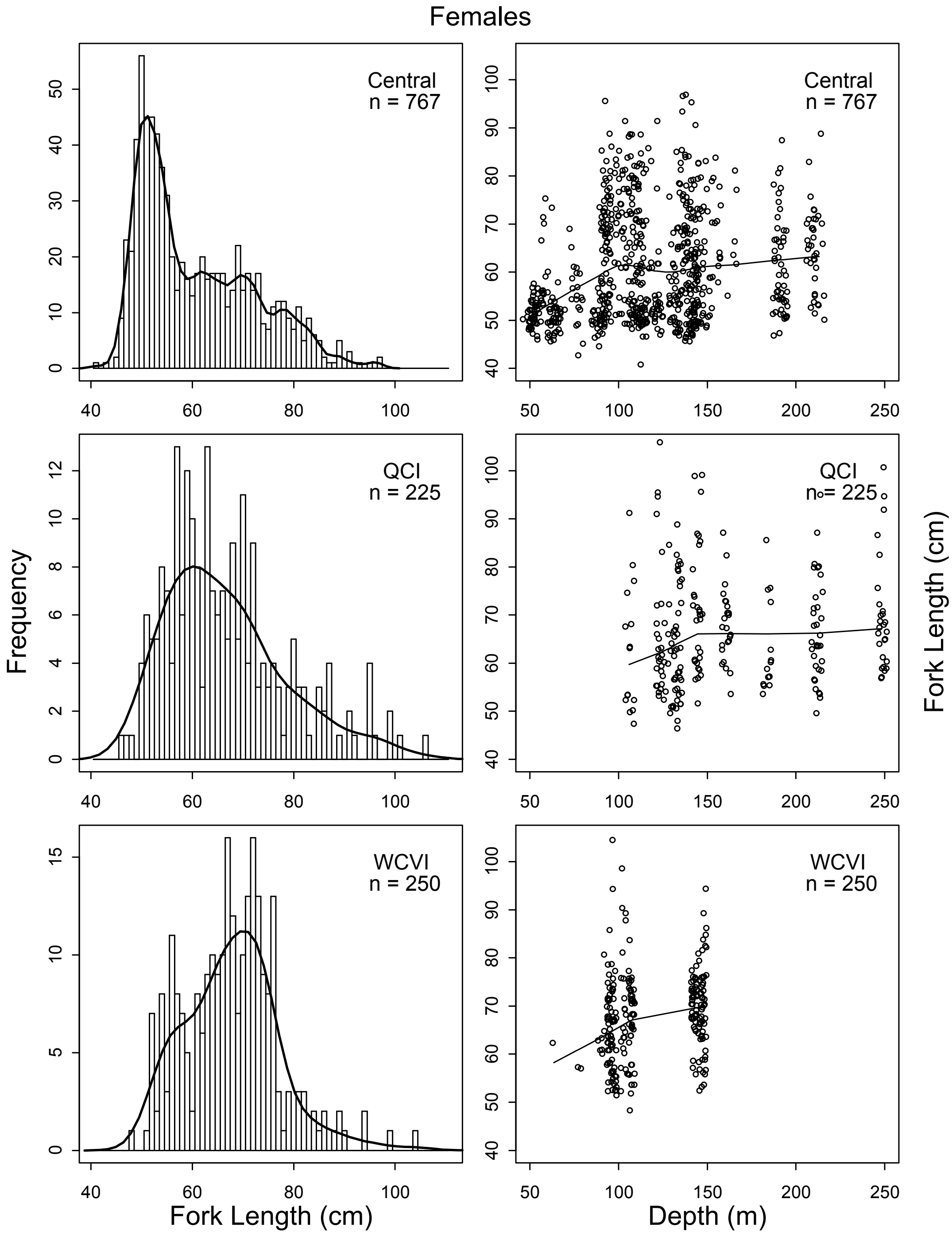


Figure L.2 Continued.

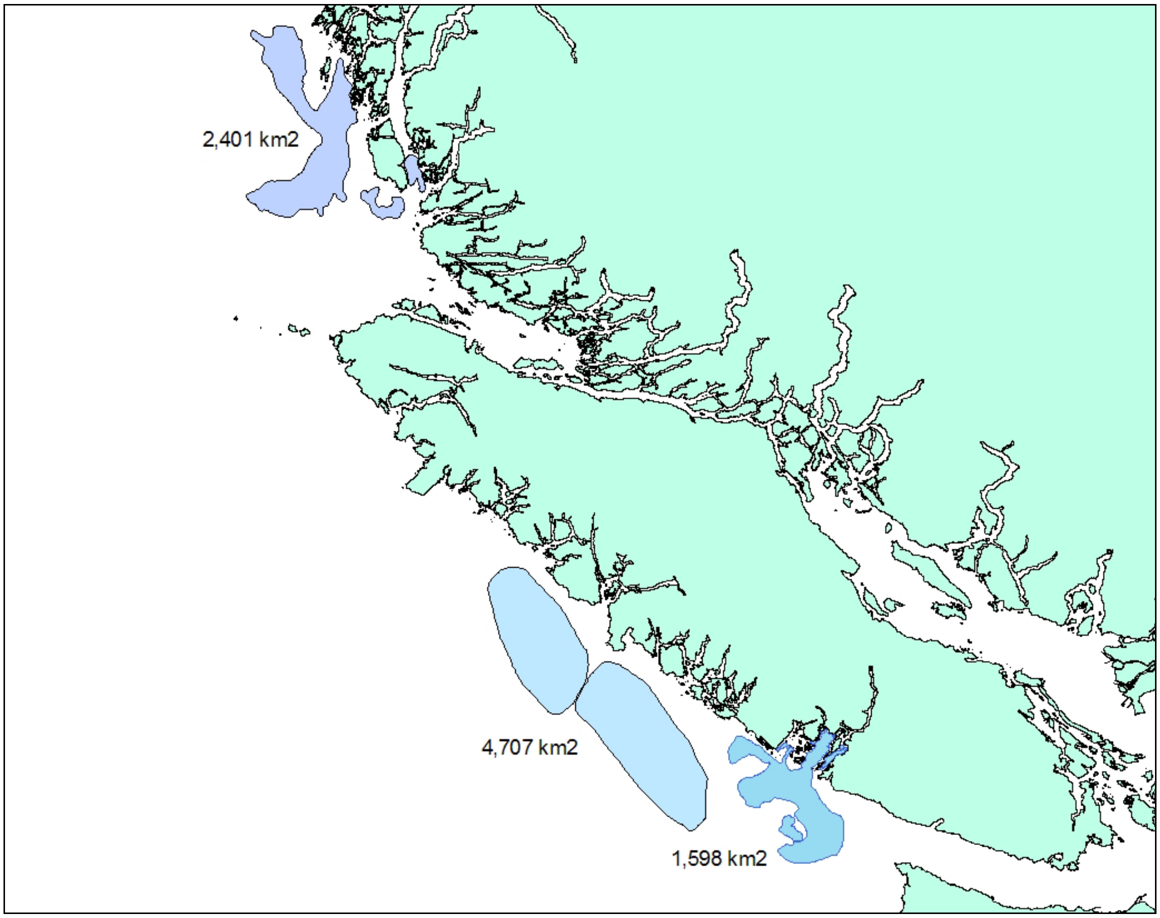


Figure L.3 Locations of the shrimp survey in Queen Charlotte Sound (areas 107-111) and the west coast Vancouver Island (areas 123, 124, and 125).

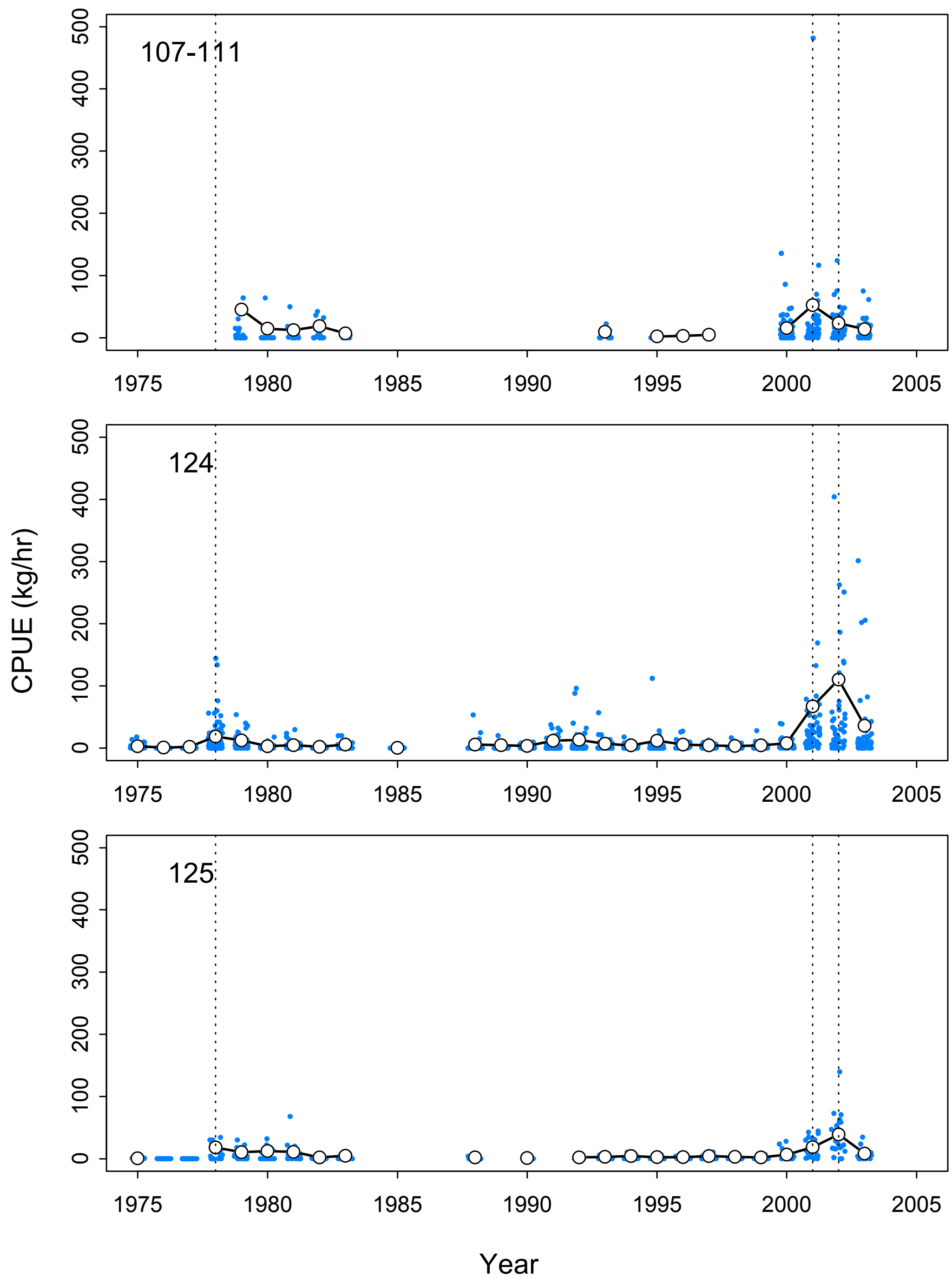


Figure L.4 Observed catch densities (kg/km^2) of sablefish in shrimp surveys by area. Solid blue circles show individual sets. Open circles and connecting lines show means for positive catch densities. Two observations (area 124: 1782 and 1890 kg/h in 2001 and 2002, respectively) are clipped from the centre panel.

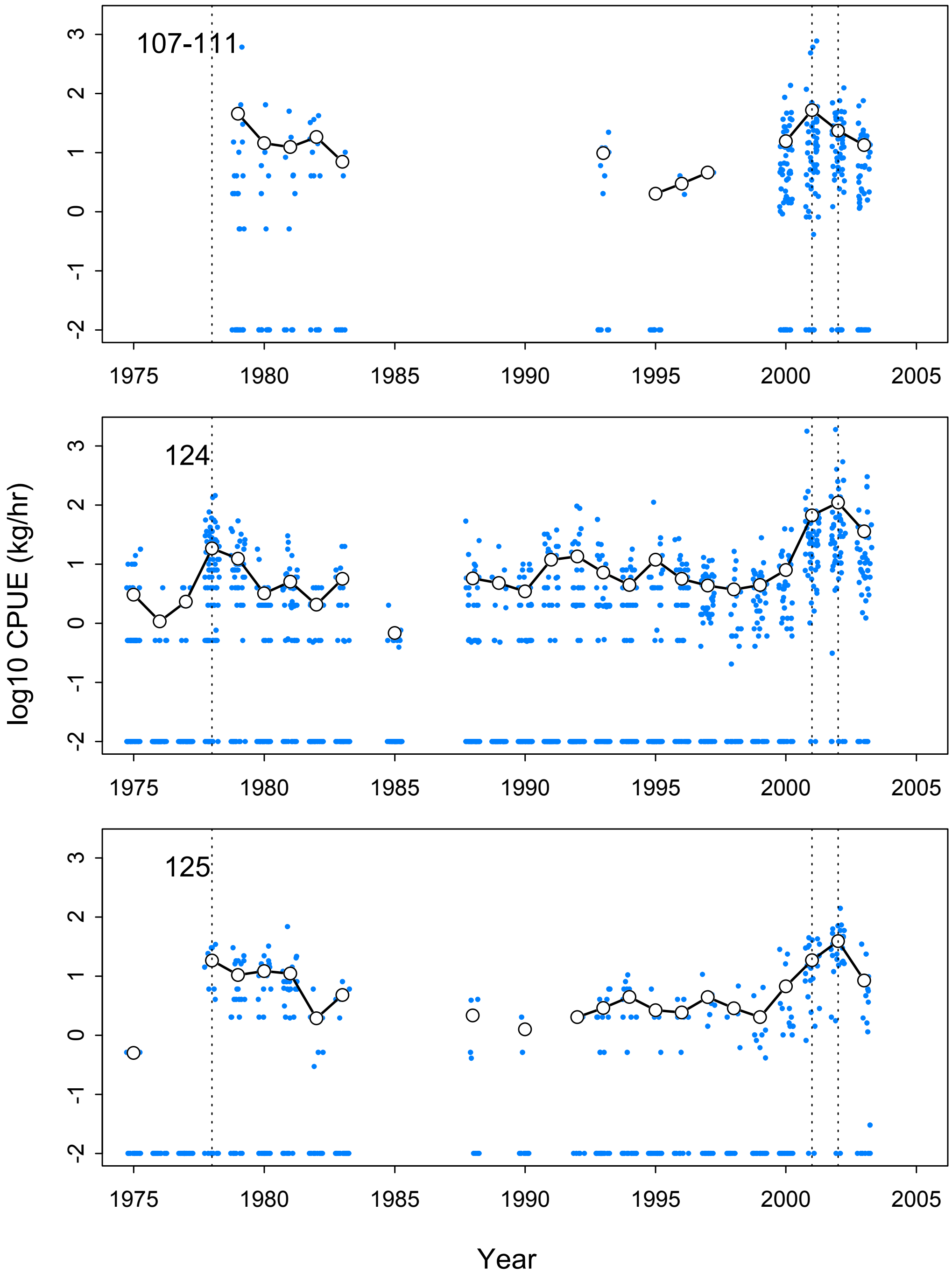


Figure L.5 Observed catch densities ($\log_{10}$ kg/h) of sablefish in shrimp surveys by area. Solid circles show individual sets. Open circles and connecting lines show means for positive catch densities. Sets at -2 on the y-axis are those with zero catch of sablefish.

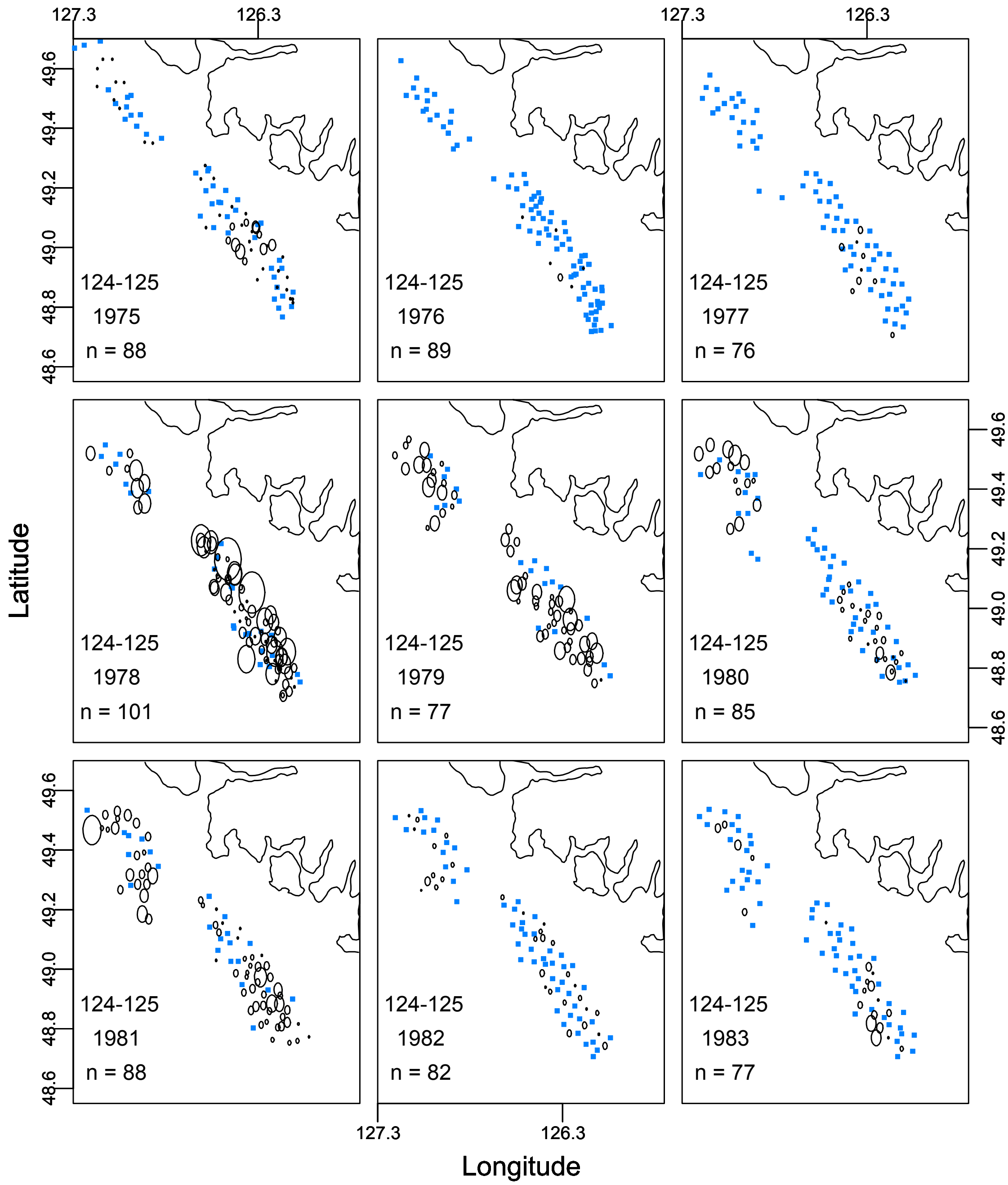


Figure L.6 Spatial distribution of shrimp survey sets for areas 124 and 125 by year. Filled blue rectangles indicate sets with zero catch of sablefish. Open circles are sized proportional to the catch rate (kg/h) for sets that caught sablefish The number of sets is indicated in the lower left corner of each panel.

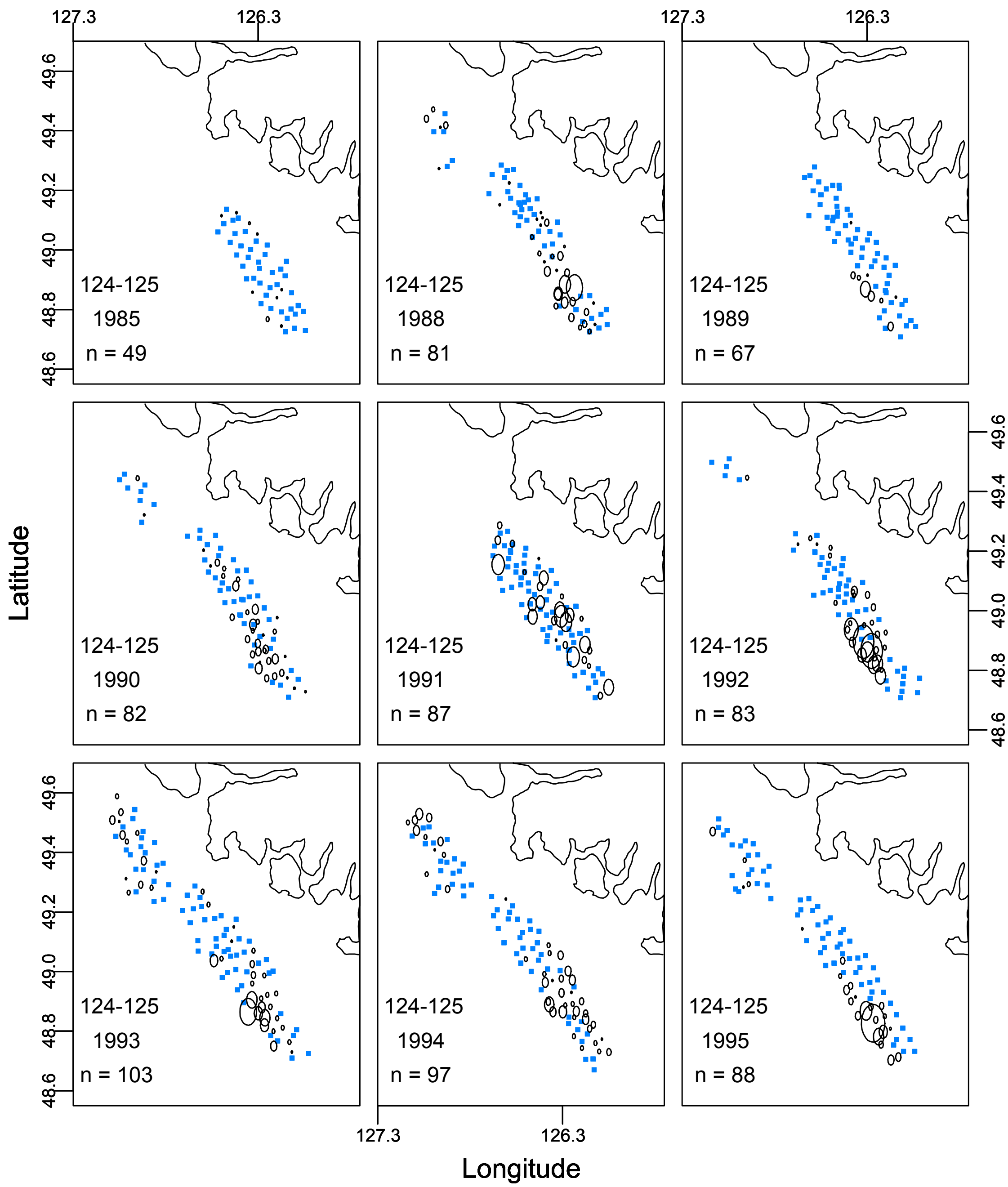


Figure L.6. Continued.

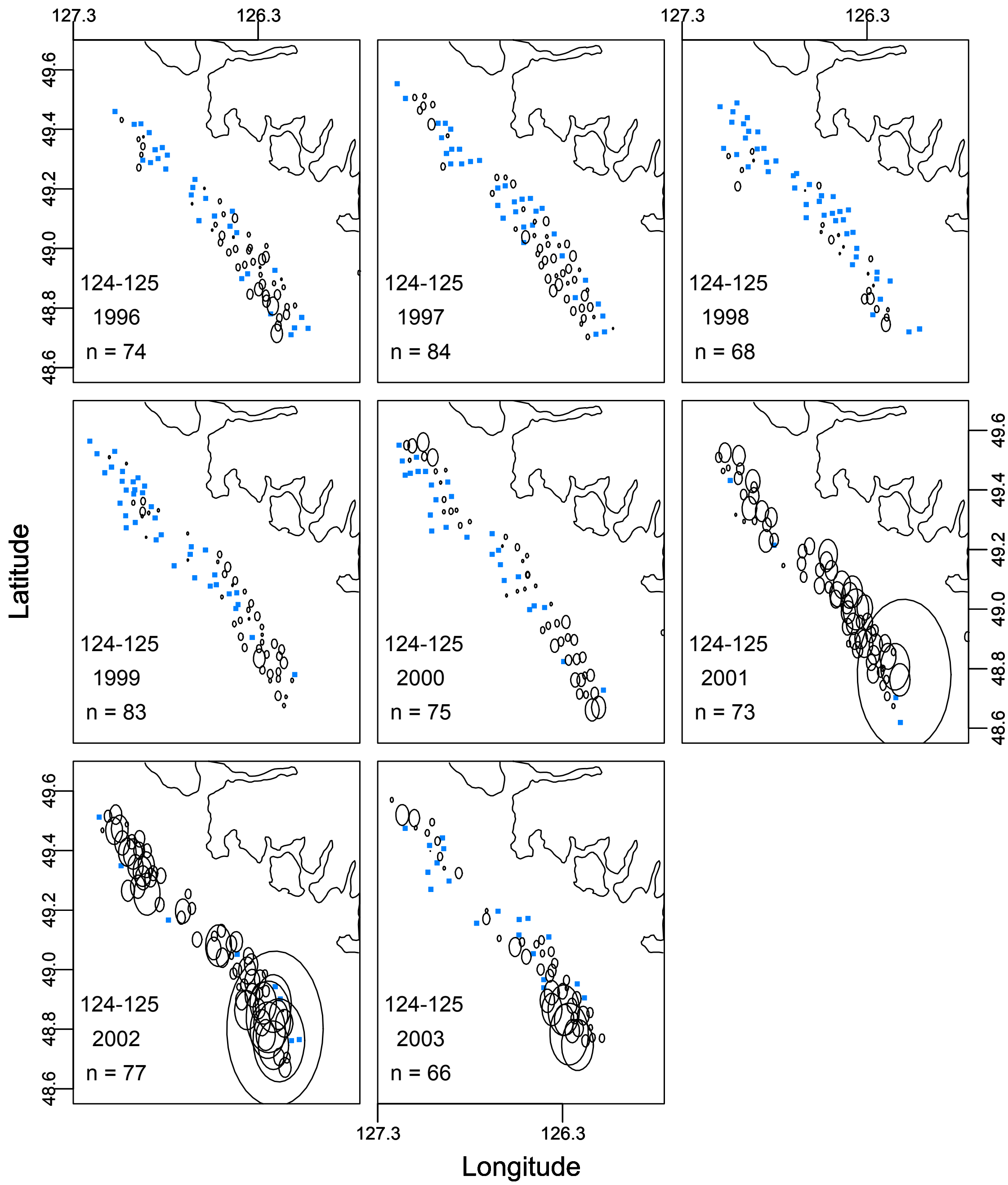


Figure L.6 Continued.

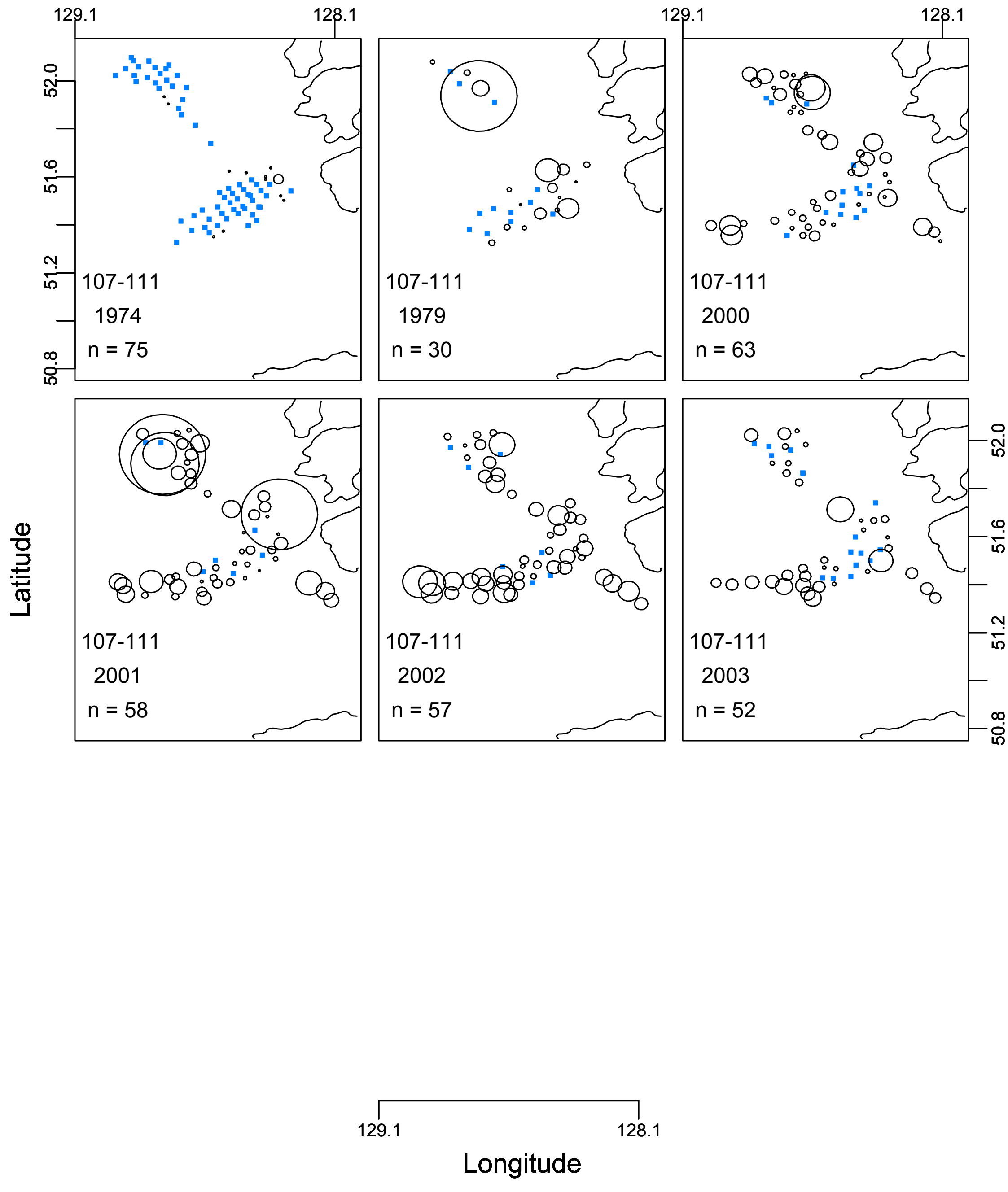


Figure L.7 Spatial distribution of shrimp survey sets for areas 107 to 111 by year. Filled blue rectangles indicate sets with zero catch of sablefish. Open circles are sized proportional to the catch rate (kg/h) for sets that caught sablefish The number of sets is indicated in the lower left corner of each panel.

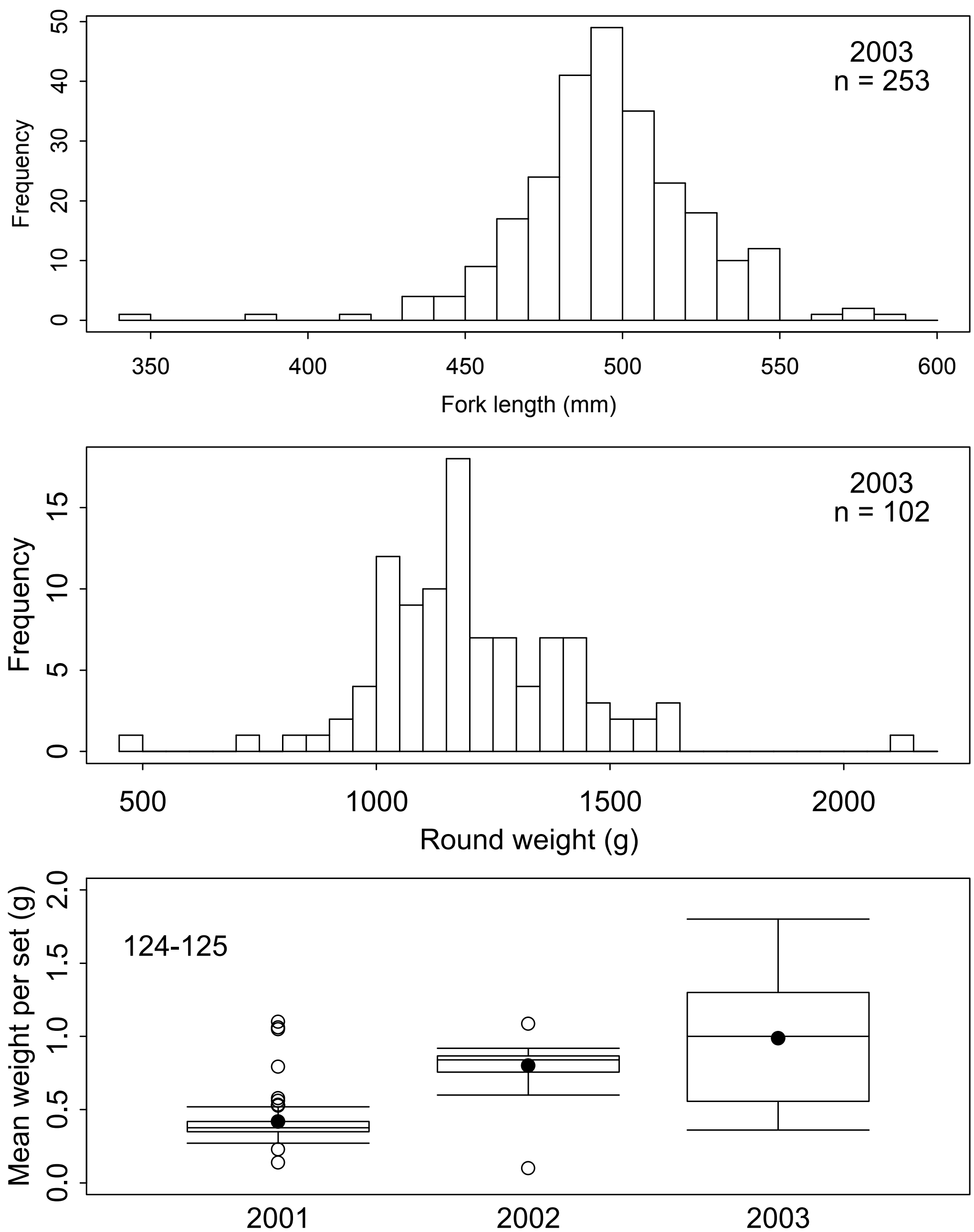


Figure L.8 Length and weight frequency distributions of sablefish caught in areas 124 and 125 during the 2003 shrimp survey (upper and middle panel). Boxplots in the lower panel show the distributions of mean weights (total kg/number caught) of sablefish for 2001 to 2003.

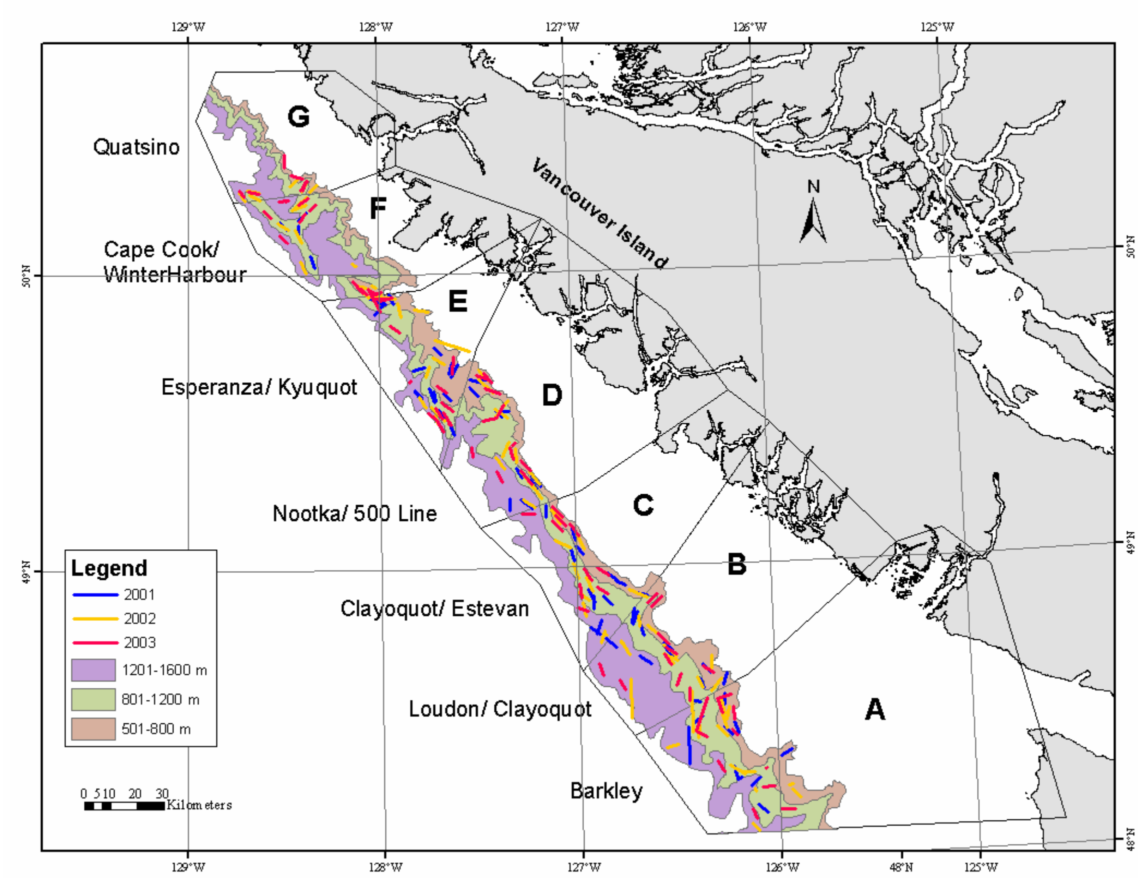


Figure L.9 Map of the seven survey regions and 3 depth strata used for the 2002 and 2003 thornyhead trawl survey. Note that region "G" was not fished in 2001. Locations of the trawl sets are shown by the coloured lines.

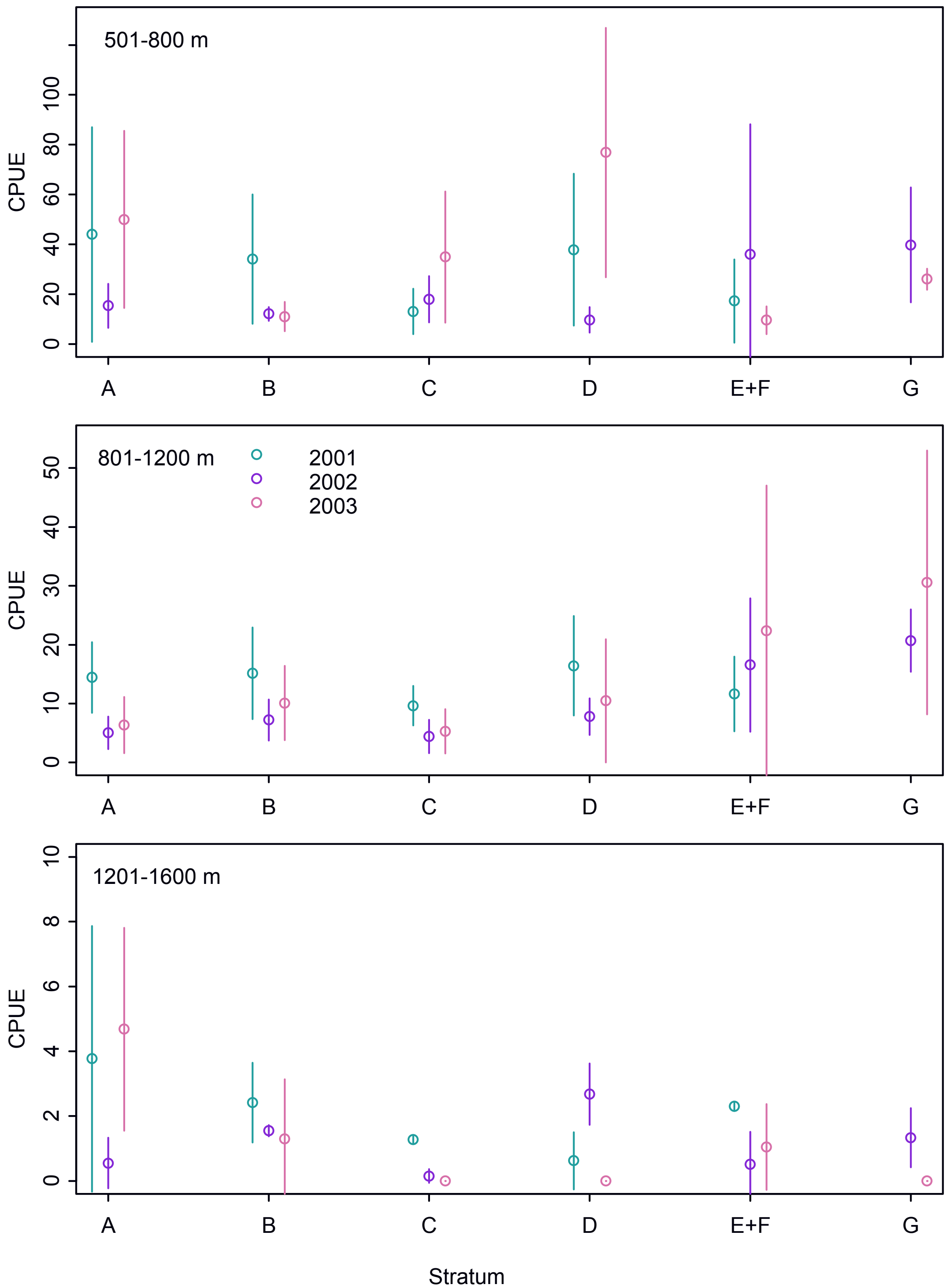


Figure L.10 The estimated mean (circle, plus/minus 1 standard deviation shown by vertical lines) sablefish CPUE from the 2001 to 2003 thornyhead survey by areal and depth strata.

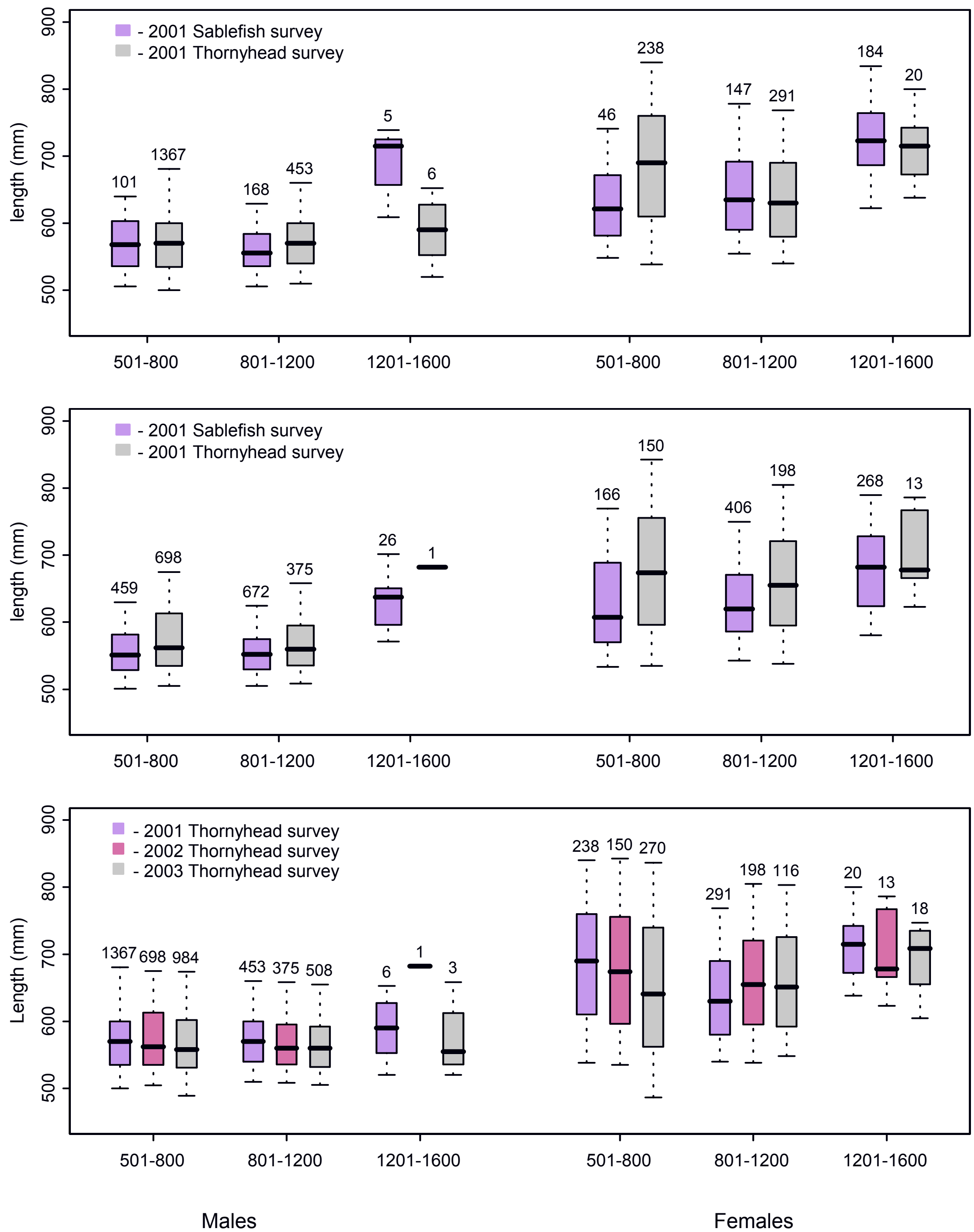


Figure L.11 Quantile plots of the length distribution of sablefish sampled during the thornyhead and sablefish surveys in 2001 (upper panel) and 2002 (middle panel). The lower panel compares length distributions for the three thornyhead surveys. The quantile plots show the median, the inter-quartile range, and the 5th and 95th quantiles of the length distributions.

APPENDIX M STATUS OF SABLEFISH IN U.S. WATERS

M.1 GULF OF ALASKA SABLEFISH M-1
M.2 CONTINENTAL U.S. PACIFIC COAST SABLEFISH M-2
M.3 LITERATURE CITED M-4

M.1 Gulf of Alaska sablefish

Data sources: Catch (1960-2002) was available from Japanese longline, Japanese trawl, U.S. longline, and U.S. trawl fisheries. Effort (1964-1981) and fish lengths (1963-1980) were available from the Japanese longline fishery, while only fish lengths (1964-1971) were available from the Japanese trawl fishery. The U.S. longline fishery data yielded effort, lengths, and discards (1990-2003) and ages (1999-2002). The U.S. trawl fishery provided lengths (1990,1991,1999) and discards (1990-2002). The Japanese-U.S. longline survey produced measurements of catch, effort and lengths (1979-1994). The domestic longline survey provided catch, effort, lengths (1990-2003) and ages (1996-2002).

Assessment methodology: The model is an age-structured sequential population reconstruction tuned to catch rate indices derived from longline surveys and commercial fishery (Sigler 1999). Age classes 2 to 31 (plus group) are included in the model with an ageing error matrix based on known-age otoliths (Heifetz et al. 1999). Model structure includes gear-specific selectivities for the longline survey (asymptotic), longline fishery (asymptotic), and trawl fishery (dome-shaped). Separate estimates of catchability for the Japanese longline fishery, domestic longline fishery, U.S. longline fishery, and cooperative longline survey are included. Natural mortality was estimated in the model to be $\widehat{M} = 0.107$, similar to the estimate of 0.106 obtained in 2002 (Sigler et al. 2002). Growth and maturity parameters were estimated independently of the assessment model and enter the model as fixed parameters.

Stock Status. Gulf of Alaska sablefish spawning abundance declined during the 1970s due to fishing mortality, but recovered due to contributions from exceptional year classes in the late 1970s and reached a peak in 1987 (Sigler et al. 2003, Figure M.1). The population declined over the course of the late 1980s and 1990s until 2000. A modest increase in population abundance has occurred from 2000 to 2003. The 2003 stock assessment included the following results:

- The longline survey abundance index decreased 7 percent from 2002 to 2003;
- Relative abundance in 2003 is 10 percent higher than in 2000;
- The fishery abundance index increased by 6 percent from 2000 to 2002 (2003 data unavailable);
- Spawning biomass is projected to decrease less than 1 percent from 2003 to 2004;

- The 1997 year class is projected to comprise 31 percent of the 2004 spawning biomass, up from a projected 24 percent in 2003;
- The 1998 year class may be above average, though it is not expected to be as strong as the 1997 year class and is relatively weak in the model estimates (Figure M.2);
- Projected 2004 spawning biomass is 40 percent of unfished biomass, but is projected to fall to 36 percent in 2004, 34 percent in 2006, and 33 percent in 2007 under the maximum permissible yield specified by the U.S. adjusted $F_{40\%}$ harvest policy;
- A long term decline in the East Yakutat/Southeast area is a serious concern to U.S. biologists, since that area is considered part of the core spawning region;
- Abundance is now considered to be at a moderate level of 221,000 t spawning biomass (males plus females);
- Gulf of Alaska sablefish are not overfished.

The projected decline in spawning biomass through 2007 depends on the actual harvests and future average recruitment, and the ultimate strength of the 1997 and 1998 year classes.

Fishery decision rule. A target fishing mortality of $F_{45\%}$ with a $F_{40\text{-}10}$ adjustment (a proxy for maximum sustained yield) was applied to current biomass estimates in order to project future stock status under constant harvest and various recruitment assumptions.

Yield recommendation. Maximum permissible 2004 yield under an adjusted $F_{40\%}$ strategy is 25,400 t. Since this yield represents a 22 percent increase while abundance is projected to decrease slightly, a yield of 23,000 t or 20,700 t was recommended by the assessment team. The maximum permissible yield of 25,400 t is projected to reduce the spawning biomass below the benchmark $B_{30\%}$ in five years with probability 0.27.

The survey relative abundance index for the Gulf of Alaska has declined about 54 percent over the period 1991 to 2003, and about 27 percent since 1999 (Figure 3.6 in Sigler et al. 2003, Figure M.3). The index showed a modest increase in 2002 that was coincident with positive signs in northern B.C. from the 2002 standardized survey, but declined in 2003 from 287,133 to 245,367 (Figure M.3). Alaskan tag movement studies indicated small fish move north and west from their release sites, and return eastward as a function of age. Thus, biomass in the southeast region is expected to lag behind more westward regions as strong year classes recruit (Sigler et al. 2003, p. 12). However, U.S. analysts have noted the continued decline in the survey index as a cause for concern. In contrast, commercial catch rates (observed lbs/hook) increased from 2002 to 2003 in this region (Figure M.4).

M.2 Continental U.S. Pacific coast sablefish

No new assessment of sablefish in the waters of the continental United States is scheduled until 2005. Thus, this summary of stock status is based on the results of the 2001 stock assessment.

Data Sources. Landings (1956-2001) by major gear type (longline, trap, trawl) were available along with commercial fisher logbook data (1978-1988). Fishery independent abundance indices were available from shelf trawl (1980-2001) and slope trawl (1988-2001) surveys. Trap surveys were conducted by NMFS (1979-1981, 1983, 1985, 1987, 1989) in the northern Vancouver and Columbia INPFC areas, while Eureka, Monterey and Conception were surveyed in the south (1984, 1986, 1988, 1991). The trap surveys provided abundance indices and size-stratified abundance indices. A fishery-dependent abundance index was obtained from trawl fishery logbooks. Size and age distributions were obtained from the longline, trawl, and trap fisheries (1986-2001), and from the shelf and slope trawl surveys. Age-distributions were constructed using age-length keys. Size distribution data were obtained from the longline and trawl fisheries.

Assessment methodology. The assessment model is based on stock synthesis (Methot 1989) population reconstruction with age-structured and length-structured components, tuned to five abundance indices: (1) the AFSC shelf survey biomass estimates (1980-1998), (2) the AFSC and NWFSC slope survey biomass estimates (1988-2000), (3) the NMFS northern trap survey for "medium" and "large" size sablefish (1971-1989), (4) the NMFS south trap survey for "medium" and "large" size sablefish (1984-1991), and (5) the logbook CPUE estimated using a general linear model (1978-1988). Dome-shaped selectivity was adopted for fishery and trawl survey indices and some selectivity parameters were time-varying. Ageing error was modeled as a function of among reader agreement. A Beverton-Holt stock-recruitment function was utilized for generating annual recruitment. Natural mortality was fixed at $M = 0.07$.

Stock Status. The 2001 assessment of sablefish stocks of Washington, Oregon, and California north of Point Conception indicated that poor recruitment over the last ten years contributed to a significantly decreased spawning biomass (Schirripa and Methot 2001). In all model configurations examined, the ratio of the current estimate of spawning stock biomass to the virgin state was at 25 percent, below which the stock is considered overfished under U.S. federal legislation. Spawning stock biomass was estimated to have declined from a high of 122,000 t in 1980 to a low of about 60,000 t in 2000. An update of the continental U.S. sablefish assessment for 2002 (Schirripa 2002), which added data from 2001 fishery and survey sources, produced an increase in the absolute biomass estimate to 72,000 t, but there was little change in the ratio of current spawning stock biomass to virgin biomass. Results from the shelf and slope trawl surveys indicated two relatively strong incoming cohorts corresponding to the 1999 and 2000 year classes. The 2001 shelf survey biomass estimates are the highest in the 1980 to 2001 time series.

Fishery decision rule. A target fishing mortality of $F_{45\%}$ with a $F_{40\text{-}10}$ adjustment (a proxy for maximum sustained yield) was applied to current biomass estimates in order to project future stock status under constant harvest and various recruitment assumptions.

Yield recommendation. The Scientific and Statistical Committee of the Pacific Fishery Management Council (PFMC) recommended an optimum yield of 3,200 t for the 2002 fishing season, a reduction of 54 percent from the 2001 harvest. The Groundfish

Management Team of the PFMC suggested a three-year strategy that required a reduction in harvest to 4,000 t in 2002. The PFMC adopted a yield of 4,500 t (a 36 percent reduction from the 2001 harvest) citing evidence from the 2001 National Marine Fishery Service (NMFS) shelf survey of a strong 2000 year class. In 2003, the yield was increased from 4,500 t to about 7,000 t. This increase in yield was the consequence of a change in the estimate of the catchability parameter for the slope trawl survey. The survey catchability shifted from q=0.601 to q=0.460, in part because young fish seen in the 2001 shelf survey were not subsequently observed in the 2002 slope survey. This in turn changed the yield range from (3877-4630 t) to (7640-8437 t). The U.S. STAT review team noted that there was no means of determining whether the revised estimate of q was superior to the original 2001 estimate.

M.3 Literature Cited

Heifetz, J., Anderl, D., Maloney, N.E., and T.L. Rutecki. 1999. Age validation and analysis of ageing error from marked and recaptured sablefish, *Anoplopoma fimbria*. Fish. Bull. **97**: 256-263.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality in northern anchovy. Amer. Fish. Soc. Symp. **6**: 66-82.

Sigler, M. F. 1999. Abundance estimation of Alaskan sablefish with an age-structured population model. Fish. Bull. 97: 591-603.

Sigler, M.F., C.R. Lunsford, J.T. Fujioka and S.A. Lowe. 2002. Alaska sablefish assessment for 2002. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2003. Available from North Pacific Fishery Management Council, 605 West 4th Avenue, Suite 306, Anchorage, Alaska 99501-2252.

Sigler, M.F., C.R. Lunsford, J.T. Fujioka and S.A. Lowe. 2003. Alaska sablefish assessment for 2003. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2004. Available from North Pacific Fishery Management Council, 605 West 4th Avenue, Suite 306, Anchorage, Alaska 99501-2252.

Schirripa, M.J. and R. Methot. 2001. Status of the sablefish resource of the U.S. Pacific coast in 2001. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

Schirripa, M.J. 2002. Status of the sablefish resource off the continental U.S. Pacific coast in 2002. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR 97220-1384.

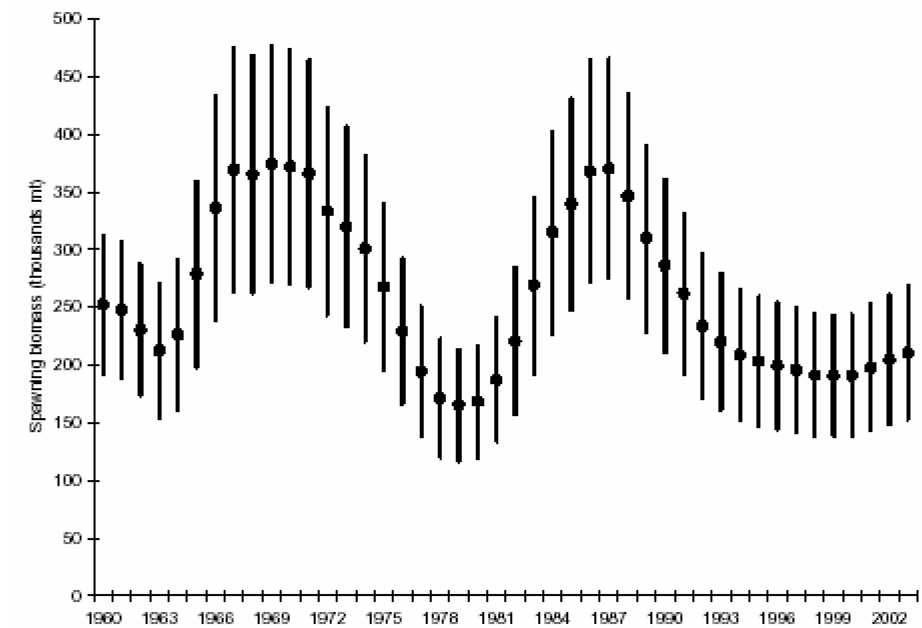


Figure M.1 Gulf of Alaska model estimates of male and female spawning biomass (thousands t) +/- 2 standard errors by year. Standard error estimates are based on covariance matrix from age-structured model output and do not include variability of the independently estimated parameters. From Sigler et al. (2003).

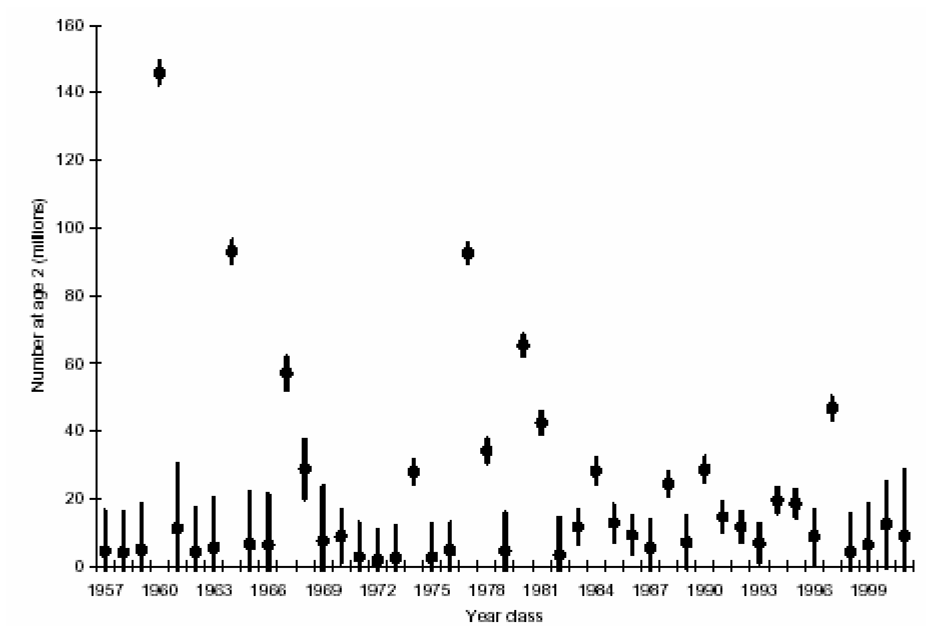


Figure M.2 Gulf of Alaska model estimates of the number of age-2 sablefish (millions) +/- 2 standard errors by year class. Standard errors based on covariance from age-structured model output do not include the variability of the independently estimated parameters. From Sigler et al. (2003).

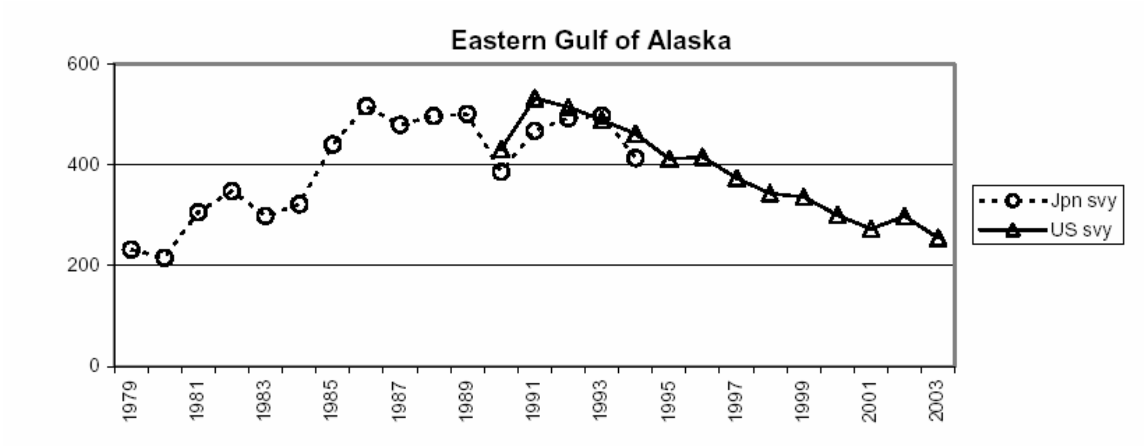


Figure M.3 Annual relative abundance (weight) determined from Japan-U.S. and U.S. domestic longline surveys for the eastern Gulf of Alaska. Values for the U.S. survey were adjusted to account for the higher efficiency of the U.S. survey gear. From Sigler et al. (2003).

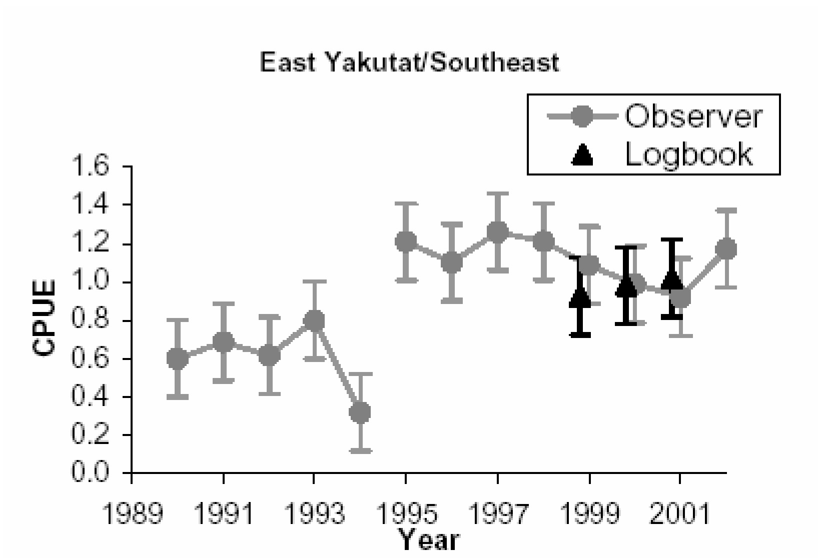


Figure M.4 Mean fishery catch rates (lbs/hook) for east Yakutat/Southeast Alaska by year. Vertical bars represent 95 percent confidence intervals. The fishery changed from open access to quota management in 1995. From Sigler et al. (2003).

APPENDIX N ANALYSIS OF 2001 ESCAPE-RING STUDY DATA

N.1 INTRODUCTION N-1
N.2 BACKGROUND N-2
The 1997 escape-ring study *N-2*
Study design for 2001 escape-ring work *N-2*
Length-Girth Relationship *N-4*
N.3 RESULTS AND DISCUSSION N-7
Study Implementation and Data Preparation *N-7*
Modelling escape-ring relative selectivity *N-8*
N.4 IMPACT ON STOCK ASSESSMENT N-15
N.5 LITERATURE CITED N-19

N.1 Introduction

The use of escape-rings in the sablefish commercial trap fishery became mandatory in 1999, though some fishermen began using them in 1998. The escape-ring regulation followed a study, initiated by the Canadian Sablefish Association (CSA), which demonstrated the efficacy of escape-rings in reducing the catch of smaller, sub-legal sablefish (Saunders and Surry 1998). Smaller fish are able to leave the traps through the escape-ring, reducing the number that are caught and subsequently released with possible associated mortality.

There are a number of reasons why results from the initial 1997 escape-ring study may not reflect how escape rings function in the current commercial fishery. One of these is that, during the 1997 study, traps had only one escape ring whereas in the current commercial fishery traps have two escape rings. Additionally, results from the 1997 study were equivocal about a number of potentially important factors. These factors included whether traps with escape-rings outfished those without the rings and whether the escape-ring selectivity function differed among long versus short and inshore versus offshore sets.

This report presents analyses of escape-ring data collected during the fall 2001 sablefish survey. Models are fit to these data to estimate length-based selectivity functions, and to determine if soak duration, mean fish size, catch rates, or sex are significant covariates of this function. Length-girth data are analyzed to estimate minimum fish lengths at which full selectivity should occur. Finally, the estimated escape-ring selectivity function is used to estimate some quantities required for sablefish stock assessments.

N.2 Background

The 1997 escape-ring study

The 1997 escape-ring study followed a fixed effects design. The three-way design included an inshore/offshore factor a 24/48 hour set duration factor and 5 levels of trap modification. For each combination of inshore/offshore and 24/48 hour soak there were 3 replicates (i.e., sets). Each replicate had 11 control traps and 11 traps for each of 4 treatments. The four treatments were escape-rings with diameters of 3 1/2, 3 7/8, 4 1/8, and 4 1/2 inches. Control traps did not contain an escape-ring.

Analyses of the 1997 escape-ring data indicated there was no significant difference in the selectivity functions for inshore versus offshore sets and short versus long duration sets (Haist and Hilborn 2000). However, the magnitude of the observed differences was fairly large which would have substantial effects on quantities of interest for stock assessments. With larger sample sizes the observed differences would have been significant.

An interesting result of the 1997 study was the escape-ring traps appeared to outfish the traps without escape-rings (Saunders and Surry 1998). That is, sablefish appeared to be preferentially attracted to traps that had escape-rings in them. Although this apparent preference was not statistically significant (Appendix C in Haist and Hilborn 2000), the magnitude of the relative difference was large, with potential major effects on stock assessment quantities. Researchers involved in the 1997 study put forward two hypotheses to explain why escape-ring traps appeared to out fish control traps. These were: (1) sablefish were attracted to the metal escape-rings, and (2) sablefish were attracted to the higher level of activity in escape-ring traps that resulted from fish trying to exit the traps.

The design of inshore versus offshore blocks had limitations because there are a number of differences between the inshore and offshore fisheries that could be causative factors in the escape-ring selectivity function. Key differences included: sablefish size distributions, with generally smaller sablefish caught in inshore waters; and fish density or catch rates, with higher catch rates in inshore waters.

Study design for 2001 escape-ring work

In 2001 a new escape-ring study was conducted. The study was planned to continue over a number of years, with intermittent analyses of the data to determine if additional work was required. The objectives of the study were:

1. estimate a length-based relative selectivity function for escape-ring traps (relative to control traps) which reflects commercial trap fishery operations;
2. determine if there are significant covariates of the selectivity-length relationship which have a large effect on quantities of interest to the stock assessments.

In designing the study, consideration was given to the trade-offs of covering the range of fishing practices seen in the commercial fishery and minimizing the number of factors that would need to be modeled, thus reducing the number of replicates per factor. For this reason, the treatment was limited to one escape-ring size, 3 7/8 inches, although three sizes are used in the commercial fishery (Table N.1). The most commonly used escape-ring size is 3 7/8 inch, with this size being used in 66% of the sets made in 2002.

Table N.1 Proportion of commercial trap fishing sets using 3 1/2, 3 3/4, and 3 7/8 inch escape-rings by year.

Ring Size	1999	2000	2001	2002
3 1/2	0.29	0.35	0.15	0.11
3 3/4	0.20	0.07	0.24	0.23
3 7/8	0.51	0.58	0.60	0.66

For the 2001 phase of the study, a single set duration was selected, again to minimize the number of factors that could influence the selectivity function. The set duration selected, 36 hours, was the median trap fishery set duration for the 1995−1998 period. More recently (1999-2002), the median trap fishery set duration is slightly lower at 30 hours, and 70% of trap fishing sets are between 18 and 48 hours duration (Figure N.1).

The study was not designed to estimate catch rate differences between independently operating escape-ring and control traps. An estimate of this difference would be required to standardize commercial fishery catch rates (CPUE) before and after the introduction of escape-rings. Given the possibility that sablefish are preferentially attracted to traps with escape rings over those without rings, estimation of this difference would require comparing data from sets where all traps either had, or did not have, escape rings (i.e., ensure that there is no possibility that the escape-ring traps are competing with control traps). Given fairly high variation in catch rates between sets, such a study would be very large and expensive.

The escape-ring study had a random effects design. Three set locations were randomly selected in each of 3 strata (west coast Vancouver Island, Queen Charlotte Sound, and west coast Queen Charlotte Islands). Specific locality and depth intervals were randomly selected from the logbook database of recent commercial trap fishing sets. The objective was to mimic commercial fishing operations as much as possible. Potential covariates of a selectivity function such as fish density and fish size would be randomly sampled through the random selection of fishing sites. However, because these covariates may have greater variation over years than over geographic location, further escape-ring work in future years may be required to assess temporal interactions among covariates.

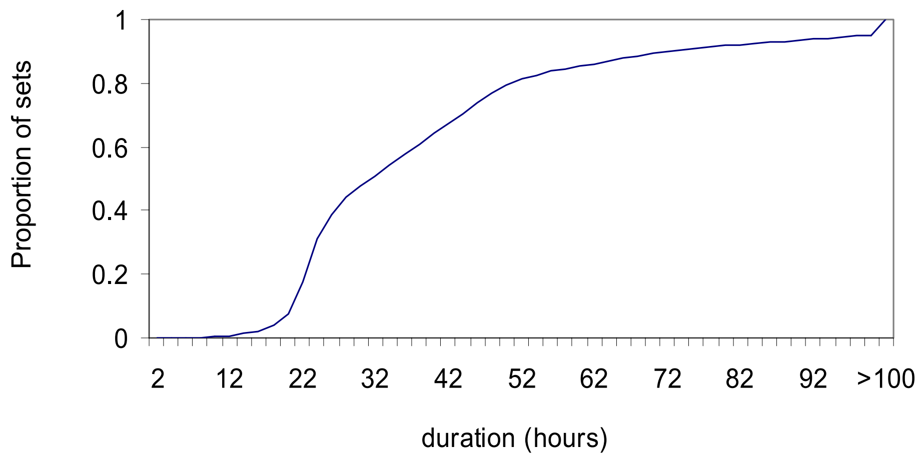


Figure N.1 Cumulative density distribution of the duration (in hours) of sablefish commercial trap fishing sets over the 1999 – 2002 period.

Length-Girth Relationship

The retention of sablefish in escape-ring traps may be more closely related to fish girth than to length. However because fish length distributions are routinely measured (and girth distributions are not), ultimately we need a length-based selectivity function. Analysis of the length-girth relationship can be useful for the escape-ring analysis through: 1) providing information about covariates that may affect the escape-ring selectivity relationship, and 2) estimating a minimum length above which sablefish cannot escape the traps because they are too large (girth is greater than escape-ring size). Information related to the second of these points may be particularly useful because lengths at full retention that were estimated for the 1997 study data were unrealistically high. As a result, arbitrary bounds were placed on some model parameters.

Between 1995 and 1999 a total of 4115 sablefish length and girth measurements were taken (Figure N.2). The 1995 and 1997 samples were collected in May/June and the 1999 samples were collected in October. A GLM analysis of the length-girth data was conducted to determine if there are any factors in addition to fish length that account for variation in fish girth. Potential covariates included fish sex, fish maturity class, and month of capture. Annual effects were not considered because month and year were confounded (Table N.2). Log transformations of both the length and girth data in conjunction with a Gaussian error structure resulted in reasonable residual patterns. Alternate transformations and error structures did not improve the model diagnostics. Fish sex, maturity and capture month were treated as covariates.

Table N.2 The number of fish girth measurements by maturity class and month.

Month	Maturity Class								
	1	2	3	4	6	8	10	11	12
May	1	0	0	0	0	1	0	9	466
June	0	0	0	0	0	0	1	8	387
October	11	193	2602	427	2	0	0	0	7

Fish length accounted for 82.62% of the variation in sablefish girth. Including the month of capture in the relationship increased the R^2 to 84.22% (Figure N.2a). The next step of including fish sex in the GLM, although producing a significant improvement in the fit (p=0.036), only increased the R^2 to 84.24%. Although including sex as a covariate in the relationship is significant, the effect is small – on average the girth of a female is 0.996 that of a male of the same length. Month effects are much larger, with fish of a given length averaging 4% larger girth in October than in May.

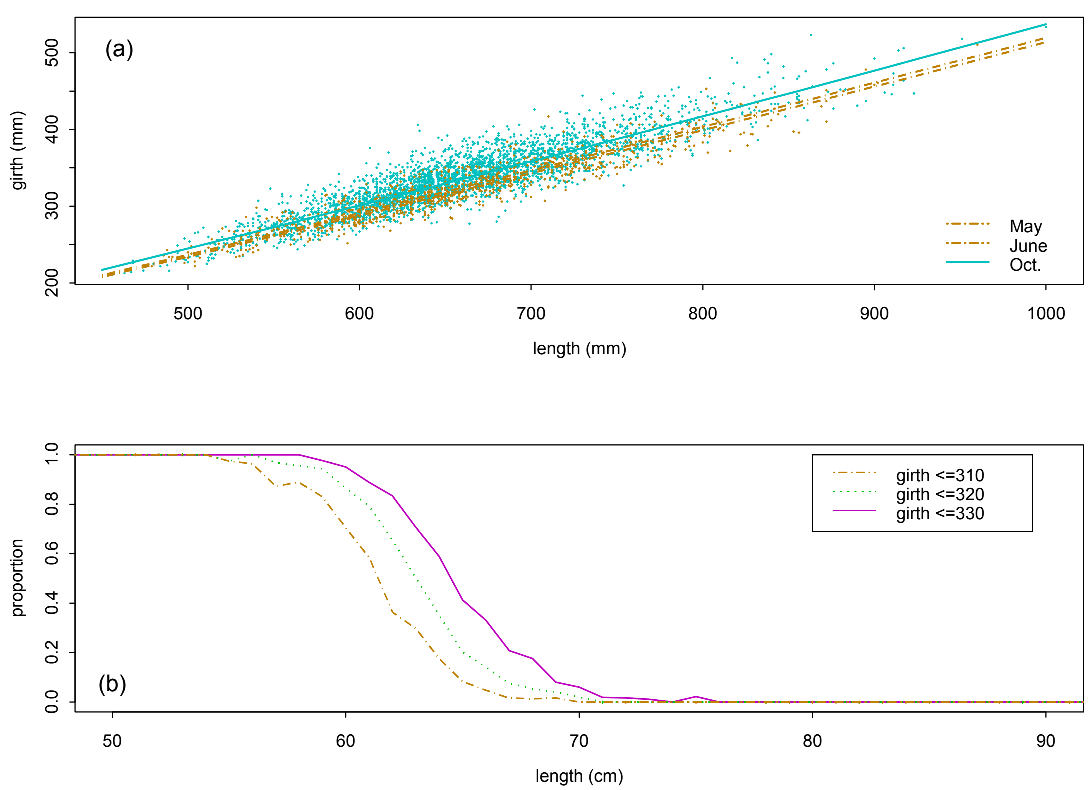


Figure N.2 (a) Girth-length observations by month of capture (points) and the estimated girth-length relationship showing month effect (lines). (b) Proportion of girth measurements that are ≤ 33 cm for each 1 cm length category. The data on which these proportions were calculated were limited to the fish sampled in October.

Fish maturity accounts for a slightly higher proportion of the variation in fish girth than does month of capture (R^2 of 84.78 vs. 84.22), though given the increased number of parameters for a model with maturity, the model with month is a more parsimonious solution. The important point to note is that there are seasonal changes in the length-girth relationship, which may result in seasonal effects in a length-based escape-ring selectivity function.

The GLM approach to analyzing the length-girth data is useful in determining factors that affect the relationship between the two, but a different approach is required to determine a minimum length above which a fish's girth is too large to allow the fish through an escape-ring. The approach used here is based on empirical quantiles of the length-girth data. An alternate approach could be based on assuming a bi-variate normal distribution for the length-girth data, however the number of observations is large enough that it is not unreasonable to use the empirical distribution.

The first step in determining a minimum length for full escape-ring retention is to have some idea of a minimum girth above which sablefish cannot pass through the escape-ring. Escape rings with a 3 7/8 inch diameter have a circumference of 30.96 cm. Thus we might expect that all fish with a girth greater than 30.96 cm will be retained in the trap. There is a small amount of additional information that might be used in this decision. During the 2001 study, the girth of fish that were trapped in an escape ring was measured (Table N.3).

Table N.3 Fish measurements for fish trapped in escape-rings.

fish comment	length (mm)	girth (mm)	sex	maturity
stuck in escape ring	696	377	2	3
stuck in escape ring	688	370	1	4
stuck in escape ring	660	368	2	3
stuck in escape ring	644	350	1	4
stuck in escape ring	705	346	1	5
stuck in escape ring	619	335	1	4
stuck in escape ring, full stomach girth 340mm, 322mm at ring	658	322	2	4
stuck in escape ring	655	307	2	3

Given that a fish with a girth of 30.7 cm was stuck in an escape-ring, and that another stuck fish had a circumference of 32.2 cm at the point where it was stuck, a reasonable range for the minimum girth for full retention is likely in the range of 30 to 33 cm.

The proportion of sablefish in one centimeter length bins that had a girth less than or equal to 31, 32, and 33 cm is shown in Figure N.2b. The data used for these calculations were limited to fish sampled in October because of the apparent seasonal differences in the length-girth relationship. These results show that for fish with a length of 69 cm. 10% have a girth less than 33 cm. For fish with a length of 65 cm., 10% have a girth less than 31 cm. Thus we might expect that the maximum length at which 90% of sablefish are retained in a trap is in the range of 65 to 69 cm.

Having a maximum length for the point where 90 percent of sablefish in a trap cannot escape is potentially very useful in modeling the escape-ring selectivity function. In the analysis of the 1997 escape-ring data, estimates of the length at which 90% of sablefish were retained in 3 7/8 inch escape-ring traps were often unrealistically high (often over 80 cm). This required *ad hoc* procedures to limit the size at full selection. However, given a reasonable estimate of the minimum size at which 90% of the sablefish will be retained, this value can be included in the model either as a constraint or in the form of a prior.

N.3 Results and discussion

Study Implementation and Data Preparation

All of the 9 sets that were specified in the experimental design were achieved (Table A-1). A minor difference from the initial study specifications resulted in control traps having escape-rings that were sewn closed rather than having no escape-rings. This departure is not likely to influence this analysis. Also, the duration of sets was quite variable (28 to 48 hours, Table A-1) compared to the study specification of 36 hour sets. Again, this is not considered to be a problem and, in fact, allows us to evaluate set duration as a potential covariate in the selectivity function.

The data from the 2001 escape-ring study was relatively clean and required little grooming, unlike data from the 1997 study. Across the 9 sets, data from 15 traps were excluded from the analysis because of potential problems with the trap operations. Reasons for rejecting data from specific traps included: the escape rings were not properly closed in control traps; there were holes in parts of the trap webbing; and there was no bait in the trap. The first of these reasons is clearly appropriate grounds for removing the data from the analysis. It may not be appropriate to remove data for the other two reasons because these represent conditions that may occur in commercial operations.

Tables A-1 and A-2 provide summary statistics for the data collected in the 1997 and 2001 escape-ring studies. The most notable difference between the two studies was the substantially lower catch rates in 2001. In 2001, catch rates in the control traps ranged from 1.0 to 8.6 fish per trap and in 1997 catch in the offshore traps ranged from 8.0 to 13.6 fish per trap. The higher catch of larger sablefish in escape-ring traps, observed in the 1997 study, is not apparent in the 2000 data (Table N.3).

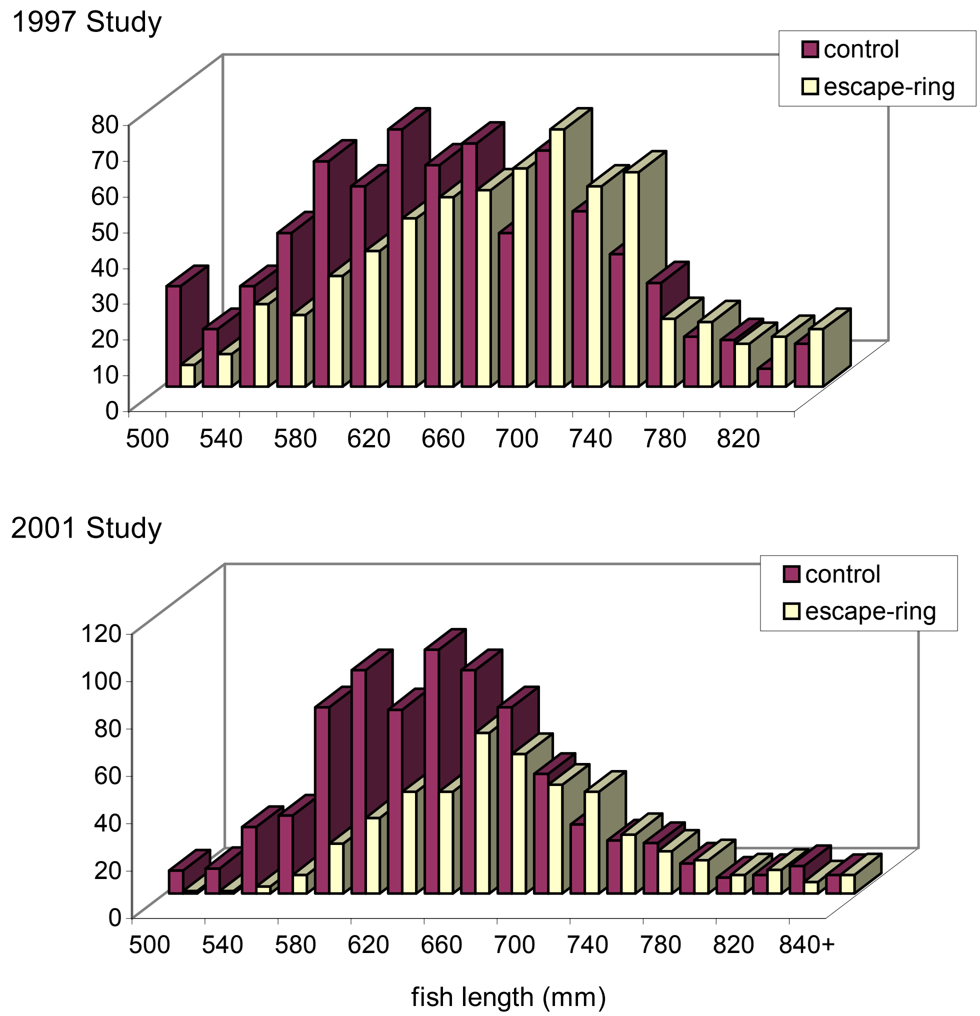


Figure N.3 Frequency distribution of fish length (by 20 mm categories) in control traps and in escape-ring traps (3 7/8 inch rings) for the 1997 and 2001 studies. The 1997 data were from offshore sets only.

Modelling escape-ring relative selectivity

The form of the escape-ring retention selectivity model used in this analysis differs from that used for the analysis of the 1997 study data in two ways. First, a different 3-parameter generalization of the logistic function, which provides better fits to the data, is used. Second, the 3-parameter model is extended to allow for covariate effects. For the 1997 data analysis, separate 3-parameter models were fit to the data from each of the design blocks (Appendix C in Haist and Hilborn 2000), which was not done here.

The objective of this modeling exercise is to estimate the relative selectivity of escape-ring traps compared to control traps as a function of fish length. The model used for this analysis follows one proposed by Gagnon (1992), which allowed for differences in efficiency (or in the case of traps, the relative attractiveness) of the two gear types. Additionally, the model accounts for differences that arise when the effective number of control traps is not equal to the effective number of escape-ring traps in a set.

For a fish to be caught in a trap, it must both enter the trap and be retained in the trap. If these two events are independent, the capture of a fish can be expressed as the product of the probability of entering the trap and the probability of being retained in the trap. First, assume that the probability that a fish enters a control trap and the probability that a fish enters an escape-ring trap is independent of fish size and depends only on the relative number of traps of each type. Second, assume that the probability of being retained in a control trap is equal to one. Given that a fish of sex *s* and length *l* is caught and retained in one of the set *i* traps, the probability that it is an escape-ring trap ($\phi_{s,i,l}$) is

$$\phi_{s,i,l} = \frac{P^e N_i^e P_{s,i,l}^r}{P^e N_i^e P_{s,i,l}^r + P^c N_i^c}$$

where

P^e	is the probability that a fish enters an escape-ring trap,
P^c	the probability that a fish enters a control trap,
$P_{s,i,l}^r$	is the probability that a fish of sex *s* and length *l* in set *i* that is caught in an escape-ring trap will be retained in the trap,
N_i^e	is the number of escape-ring traps in set *i*, and
N_i^c	is the number of control traps in set *i*.

Define δ as the relative probability of entering a control trap, $\delta = P^c / P^e$. Let r_i be the ratio of the number of control traps to the number of escape-ring traps in set *i*, $r_i = N_i^c / N_i^e$, then

$$\phi_{s,i,l} = \frac{P_{s,i,l}^r}{P_{s,i,l}^r + \delta r_i} \quad .$$

Relative gear selectivity is often modeled using a logistic function. For this analysis the form of the logistic function is generalized to a three-parameter model that encompasses the two-parameter logistic function. Additionally, the model includes parameters that allow for sex-specific (λ_s) or set-specific (η_i) selectivity effects. The probability of retaining a fish of sex *s* and length *l* in set *i* is

$$P^{r}_{s,i,l} = \begin{cases} \dfrac{1}{1+\exp\left(\dfrac{-2\ln(3)\left(l-\beta^{50}+\lambda_s+\eta_i\right)}{\beta^{50}-\beta^{10}}\right)} & l \le \alpha \\ \\ \dfrac{1}{1+\exp\left(\dfrac{-2\ln(3)\left(l-\beta^{50}+\lambda_s+\eta_i\right)}{\beta^{90}-\beta^{50}}\right)} & l > \alpha \end{cases} .$$

The model parameters β^{10}, β^{50}, and β^{90} define the lengths where there is a 10, 50 and 90 percent probability that a fish will be retained in the escape-ring traps. The model term for the sex covariate is given by

$$\lambda_s = \begin{cases} -\tau & s = 1 \text{ (males)} \\ +\tau & s = 2 \text{ (females)} \end{cases}$$

and the term for the set-specific covariates is given by

$$\eta_i = \omega\left(x_i - \left(\frac{\sum_{i=1}^{n} x_i}{n}\right)\right) ,$$

where x_i is the value of a potential model covariate for set *i*, the ω parameter measures the magnitude of the covariate effect, and *n* is the number of sets.

Data from the escape-ring study consisted of two sets of fish, those caught in escape-ring traps and those caught in control traps. For set *i,* let the number of the number of fish of sex *s* and length *l* that are caught in control traps and in escape-ring traps be $S^{c}_{s,i,l}$ and $S^{e}_{s,i,l}$, respectively. Then, assuming the fish behave independently, the negative log-likelihood of the data is

$$\ln(f) = \sum_{i}\sum_{s}\left(S^{e}_{s,i,l}\log\left(\phi_{s,i,l}\right) + S^{c}_{s,i,l}\log\left(1-\phi_{s,i,l}\right)\right) .$$

The function $\phi_{s,i,l}$ has six estimable parameters, $\beta^{10}, \beta^{50}, \beta^{90}, \tau, \omega,$ and δ, of which the first five describe the trap retention selectivity function. The parameter δ, a nuisance parameter, accounts for a possible difference in the degree to which fish are attracted to escape-ring and to control traps. Note that while this is a nuisance parameter from the perspective of estimating escape-ring selectivity, it is a key parameter if attempts are made to standardize commercial CPUE data pre and post escape rings.

A step-wise procedure was used to investigate retention selectivity models with increasing degrees of complexity (ie. number of parameters). The simplest model explored was a logistic curve, with parameters β^{10} and β^{50} estimated. In this case β^{90} is fixed at $\left(2\beta^{50}-\beta^{10}\right)$. When not estimated, the parameter δ is fixed at 1 and the parameters τ and ω are fixed at 0. We adopt the likelihood ratio test to discern significant improvement in model fit. The test statistic

$$-2\left(\ln\left(f_1\right)-\ln\left(f_2\right)\right) \quad ,$$

where the models represented by the negative log-likelihoods f_1 and f_2 have n_1 and n_2 parameters, respectively, is asymptotically χ^2 distributed with $\left(n_2-n_1\right)$ degrees of freedom. Hence at the $\alpha=0.05$ level, we would accept a model with one additional parameter as representing a significant improvement over the simpler model if the difference in the negative log-likelihood function is 1.92 or greater.

Results of step-wise model fitting to the escape-ring data is shown in Table N.4. The simplest 2- parameter logistic function has a negative log-likelihood function value of 780.82. For this model, the point where 90% of the sablefish are retained in the trap is 725.38 mm$\left(2\beta^{50}-\beta^{10}\right)$, well above the maximum value ascertained from the length-girth analysis. For models where the β^{90} parameter is estimated, the highest value for the 90% retention is 689 mm, slightly lower than the highest value calculated from the length-girth analysis (690 mm). Thus, although not significant at the $\alpha=0.05$ level, the inclusion of the β^{90} parameter in the model appears warranted in that it produces retention selectivity function consistent with the length-girth data.

Table N.4 Estimates of the negative log-likelihood $\left(\ln\left(f\right)\right)$, number of model parameters $\left(n\right)$, and estimated model parameters for alternate formulations of the trap retention selectivity function. The column "LRT" shows the model compared for the Likelihood Ratio Test.

Model		$\ln\left(f\right)$	n	LRT	β^{50}	β^{10}	β^{90}	δ	τ	ω
1.1	logistic selectivity	780.82	2		621.47	517.56	-	-	-	-
1.2	- add δ	780.70	3	1.1	630.34	519.02	-	0.92	-	-
1.3	- add β^{90}	779.80	3	1.1	637.52	497.00	687.51	-	-	-
1.4	- add δ and β^{90}	779.79	4	1.3	639.00	497.86	689.34	0.98	-	-
1.5	- add sex covariate	779.70	4	1.3	639.00	491.33	683.31	-	2.87	-
1.6	- add CPUE covariate	779.25	4	1.3	635.00	493.19	684.94	-	-	-3.19
1.7	- add mean length cov.	779.67	4	1.3	637.00	497.25	686.99	-	-	-0.08
1.8	- add set duration cov.	779.58	4	1.3	636.00	497.02	685.98	-	-	-0.59

The parameter that accounts for a potential difference in the relative attraction of escape-ring and control traps for sablefish, δ, did not produce a significant improvement in model fit when added to the retention selectivity model. Also, the parameter value estimated was very close to 1, suggesting there was no difference in the relative attraction of the two trap types. This result is contrary to that observed for the 1997 study, where sablefish appeared to be preferentially attracted to the escape-ring traps. It is interesting to note that for the 2001 study both the escape-ring and the control traps had metal rings in them, with control trap rings being sewn shut. Thus the "metal attraction" hypothesis that was proposed to explain the higher catches in escape-ring traps during the 1997 study cannot be eliminated. Also, the very low catch rates observed in the 2001 study preclude elimination of the "activity" hypothesis.

The inclusion of a sex-specific parameter did not produce a significant improvement in model fit. Also, the inclusion of the various set-specific parameters had only small effects on the value of the negative log-likelihood. However, given that only low catch rates (CPUE) were observed in the 2001 escape-ring study, and the CPUE covariate had the largest effect on the retention function, collection of additional data under conditions of higher abundance may be useful.

Although results of the likelihood ratio tests for the models shown in Table N.4 suggest the simple 2-parameter logistic function is the appropriate one to select, we choose the 3-parameter model that includes the β^{90} parameter, because of the biological rationale provided above. Results of this fit are shown in Figure N.4.

Of particular note is the difference in the trap retention selectivity function estimated for the 2001 study data and the function that had been estimated for the 1997 study data. The 2001 function is much steeper with a lower proportion retained at small sizes and a higher proportion retained at large sizes. Some of the key differences between the 1997 and 2001 study are: for the 2001 study there were 2 rings in escape-ring traps, rather than 1; the 2001 data appeared to have fewer coding errors; the 3-parameter generalization of the logistic function used for the analysis of the 2001 data was different from that used for the 1997 data. Any, and possibly all of these factors may have contributed to the different selectivity function.

Two methods for estimating model parameter uncertainty were investigated. The first approach used a bootstrap method (Efron 1982) that involved re-sampling the data with replacement and then refitting the selectivity model. The re-sampling algorithm first randomly selected fishing sets and then randomly selected traps (escape-ring and control) within the selected sets. The second approach assumed a Bayesian analysis with uninformative priors for all model parameters. The MCMC algorithm programmed in the AD Model Builder software (Otter Research 2000) was used to estimate the posterior distributions of model parameters.

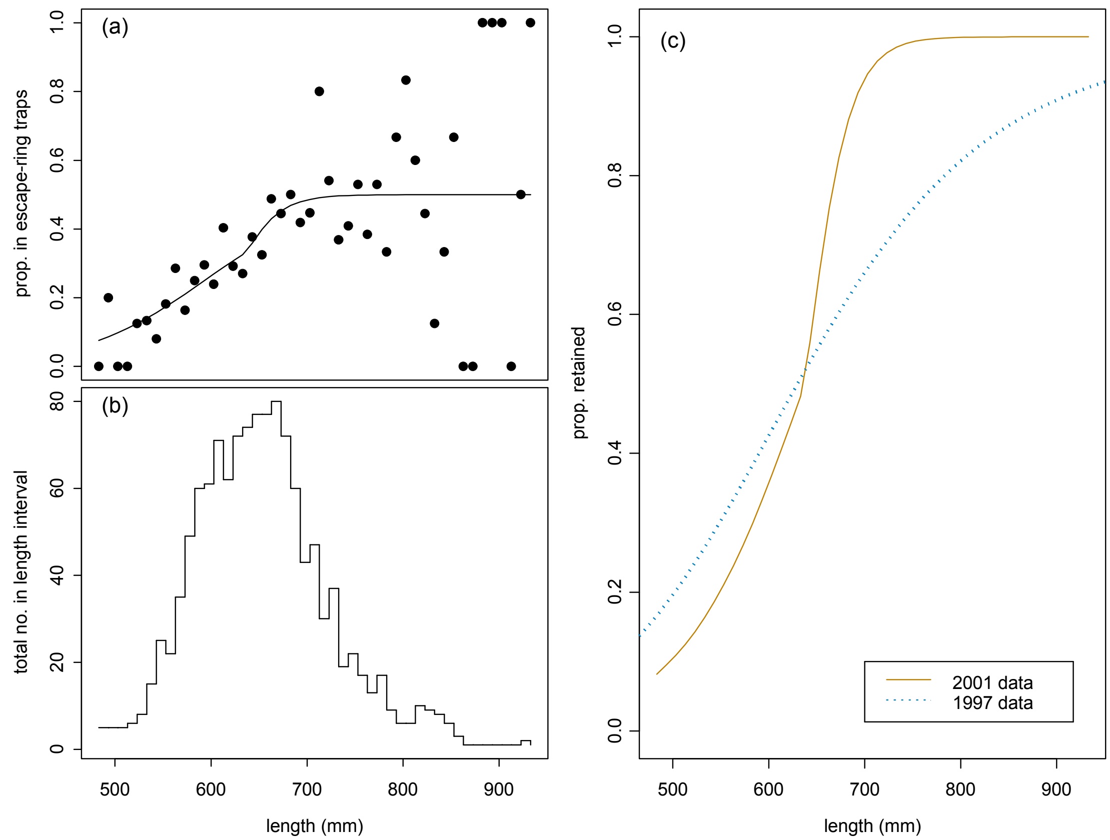


Figure N.4. (a) The observed (solid circles summarizing observations over 10 mm intervals) versus the fitted values for the proportion of sablefish in escape-ring traps. (b) The frequency distribution of total sablefish catch (control + escape-ring traps), by 10 mm intervals. (c) The escape-ring retention selectivity function estimated from the 2001 study data and the function estimated from the 1997 study data (from Appendix C in Haist and Hilborn 2000). Note that the relationship estimated for the 1997 data was restricted to the offshore sets and 3 7/8" escape-ring traps.

While the maximum likelihood fits for the selectivity model produced acceptable values for the length of 90 percent retention, some unreasonable values of this parameter were estimated with both the bootstrap and the MCMC methods. Thus it appeared necessary to formulate a prior distribution for 90 percent retention parameter. Based on the length-girth analysis, a reasonable prior for the β^{90} parameter is a normal distribution with a mean of 670 mm and a standard deviation of 15 mm. With this prior, approximately 95 percent of the distribution of the β^{90} parameter is in the 640 to 700 mm range. Results of a stepwise fitting of the retention selectivity models with the normal prior for β^{90} are presented in Table N.5.

Table N.5 Estimates of the negative log-likelihood $(\ln(f))$, number of model parameters (n), and model parameter estimates for alternate formulations of the trap retention selectivity model that includes the β^{90} prior. The column "LRT" shows the model compared for the Likelihood Ratio Test.

Model	$\ln(f)$	n	LRT	β^{50}	β^{10}	β^{90}	δ	τ	ω
2.1 logistic selectivity	783.65	2		612.44	530.46	-	-	-	-
2.2 - add δ	782.53	3	2.1	602.92	522.53	-	1.14	-	-
2.3 - add β^{90}	780.04	3	2.1	639.00	495.21	676.97	-	-	-
2.4 - add δ and β^{90}	780.00	4	2.3	639.00	491.18	675.37	1.02	-	-

In this set of model fits, the inclusion of the β^{90} parameter did produce a significant improvement. Inclusion of the δ parameter did not improve the fits and the estimated value of this parameter was close to 1. As in the analysis without the β^{90} prior, model 2.3 is selected as providing the best fit to the data.

Box plots of the estimated distributions of the β^{90} parameter, obtained from the bootstrap and the MCMC algorithm both with and without the β^{90} prior are shown in Figure N.5. For both methods, much tighter distributions are obtained for the analyses that include the β^{90} prior. In particular, the higher values for β^{90} are virtually eliminated with the inclusion of the informative prior. Parameter distributions obtained with the bootstrap and the MCMC algorithms are fairly similar when the model includes the β^{90} prior, with a slightly broader distribution from the bootstrap procedure (Figure N.5).

A quantity of potential interest for stock assessments, is the proportion of sablefish that are retained in the escape-ring traps. This quantity was estimated using the length frequency distribution observed in the control traps and the estimated retention selectivity function. The distributions of the proportion of sablefish retained in the escape-ring traps, in terms of both numbers and of biomass, are shown in Figure N.5. Results are shown only for the model runs that included the informative β^{90} prior. Here the distributions from the bootstrap algorithm are much broader than those estimated from the MCMC algorithm. Given that the estimated parameter distributions are similar for the two methods, these differences might result from the bootstrap method, through re-sampling, including uncertainty in the length distributions of sablefish in the control traps. For the MCMC algorithm the data are fixed. The median estimates for the proportion of fish, by number, retained in the escape-ring traps are 56% and 59% for the MCMC and bootstrap methods, respectively. The estimated median proportions by weight are 66% and 69% for the MCMC and the bootstrap methods, respectively.

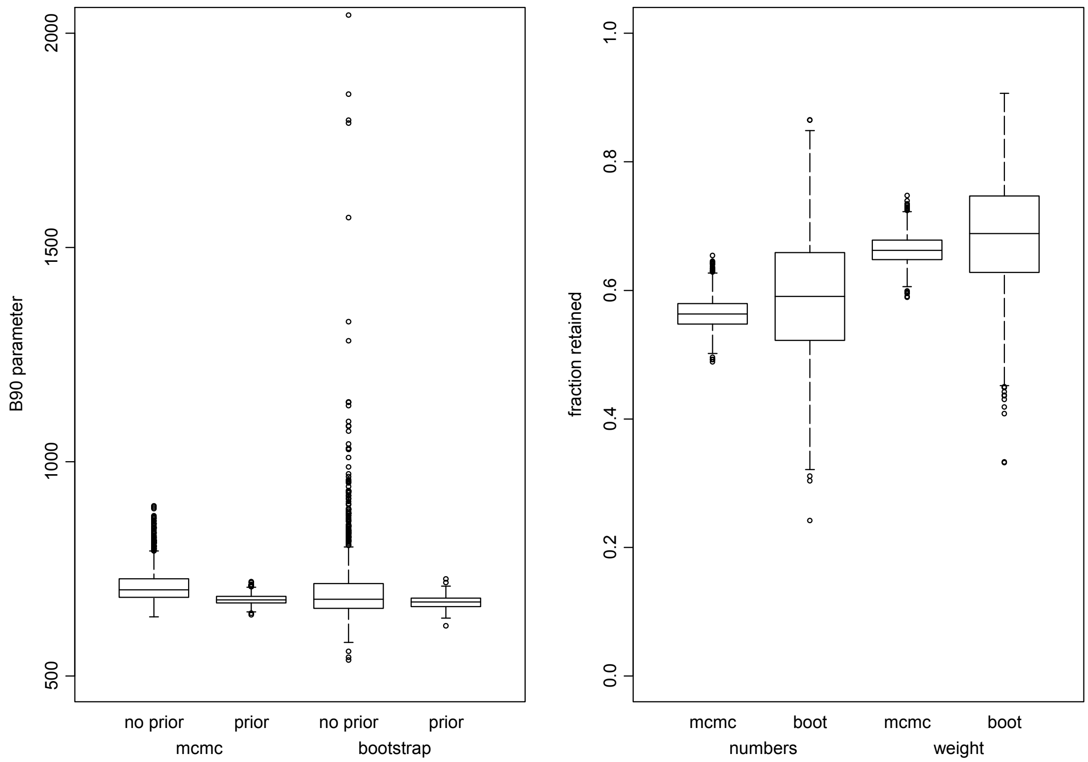


Figure N.5 Box plots of the distributions of the β^{90} parameter from the MCMC and bootstrap procedures with and without the β^{90} prior (left panel). Box plots of the proportion of sablefish by number and weight that are retained in escape-ring traps as estimated using MCMC and bootstrap methods (right panel).

N.4 Impact on Stock Assessment

The introduction of escape-rings in the commercial trap fishery can affect quantities used in the annual stock assessments in a number of ways. Escape rings introduce a different gear selectivity function, which in turn changes the magnitude of the catch relative to the landings. The size/age/sex structure of the catch and landings is also affected as are the commercial fishery catch rates (CPUE). In the sablefish fishery this situation is further complicated because not all fish that are caught are landed. Although the legal minimum size for retaining sablefish is 55 cm, fish larger than the minimum size are often released for economic reasons.

For B.C. sablefish, stock assessment analyses affected by the introduction of escape-rings include commercial trap fishery CPUE analysis, age-structured analysis, and mark-recapture analysis. Impacts on the mark-recapture analysis are described in some detail here.

As discussed previously, the current escape-ring study is not intended to address standardization of the trap-fishery CPUE. The initial escape-ring study indicated sablefish were preferentially attracted to escape-ring traps. If this is true, then CPUE standardization would require estimates of a relative attraction parameter that was obtained where escape-ring and control traps were fishing independently. Given that results from the 2001 escape-ring study do not support the differential attractiveness of the two trap types, using the escape-ring data for CPUE standardization might be feasible. However, as noted above, the 2001 control and escape-ring traps both included metal rings, and catch rates during the study were extremely low.

Currently, age-structured analyses are not conducted as part of the annual sablefish stock assessments. However, when age-structured analyses are re-introduced the effect of escape-rings on the commercial trap fishery selectivity will need to be included in the model equations. Two approaches for dealing with this issue are: 1) estimate relative retention selectivity parameters as part of the suite of age-structured model parameters, or 2) assume known age- and sex- specific escape-ring retention selectivity functions. Given the scarcity of age and sex composition data for the sablefish trap fishery across the pre- and post- escape-ring period, the latter of these options is favoured.

For the sablefish mark-recapture analysis, there are a few quantities affected by the introduction of escape-rings. The "Peterson-type" tagging analysis, which has become one of the key components of the sablefish stock assessment, relies on estimates of two quantities affected by the escape-ring retention selectivity function. These two quantities are required because a standard Peterson model requires data on the number of fish sampled for tags. For sablefish, the only quantity that is directly estimated is the tonnage landed. The required conversion factors are: (1) the ratio of the number of fish caught (i.e., sorted) to the number of fish landed; and, (2) the ratio of the average weight of fish tagged to the average weight of fish landed (Haist et al. 2001, p. 37).

The standard Peterson mark-recapture estimate of population size is,

$$N = {}^{Tn}\!/_{M} \quad ,$$

where N is the estimated number of vulnerable fish in the population, T is the number of fish with tags, n is the number of fish sampled for tags, and M is the number of fish with tags in sample n. Because there are no direct estimates of n for sablefish, we define a modified Peterson estimator that is based on quantities that are estimable. Define the following equivalencies:

$$n = CS \qquad \text{and} \quad N = {}^{B}\!/_{\bar{w}^{v}} \quad ,$$

where C is the landings in tonnes, S is the number of fish sorted per tonne of fish landed, $\bar{w}^{v}$ is the mean weight (in tonnes) of a trap-vulnerable sablefish (and hence vulnerable to tagging), and B is the biomass of the vulnerable population. The modified Peterson estimator is then:

$$B = \frac{TCS\bar{w}^v}{M} \quad .$$

Note that the term "vulnerable population" refers to sablefish that are vulnerable to the tagging program. The quantities T, C, and M are data that are readily available. Estimates of the quantities S and $\bar{w}^v$ are derived here. Because of potential inter-annual and regional difference in the number of fish sampled per tonne and in the average weight of vulnerable fish, a subscript for strata is introduced. As noted previously, we assume that small, tagged sablefish which would otherwise be released because of their size are retained and their tags returned. Therefore the numbers of fish sampled for tags is greater than the numbers that are landed. The number of sablefish that are sampled per tonne that are landed is given by

$$S_i = \frac{1}{\bar{w}_i^c}\left(1 + R_i\right) \quad ,$$

where $\bar{w}^c$ is the mean weight of fish from stratum i that are landed and R_i is the ratio of the number of fish caught and released to the number of fish that are caught and landed in stratum i.
Estimation of $\bar{w}_i^c$ and R_i requires the definition of a few additional quantities:

F_{il} the relative frequency of sablefish of length l in stratum i that are vulnerable to tagging;

w_l the average weight (in tonnes) of a fish of length l ($w_l = 2.4419\left(10^{-9}\right)l^{3.346942}$, from Table 5.6, Saunders et al 1996);

P_l^r the probability that a fish of length l that enters a trap will remain in the trap (trap retention selectivity function estimated above; note the s and i subscripts in $P_{s,i,l}^r$ are dropped here because sex and set-specific covariates were not included in the final model);

P_l^v the probability that a fish of length l that is caught in a trap is landed (from observer data, values presented below).

The quantities, F_{il}, are calculated from all sablefish survey data over the period 1980 to 1996. A more accurate procedure would be based on annual length frequencies. However, the data used here are from an old database, and annual length frequencies from the new database were not available at the time of analysis. Parameter estimates are presented for two strata – northern B.C. and southern B.C. waters in the 250 to 450 fathom interval. Note that the quantities $\bar{w}_i^v$ are also calculated based on the F_{il} length-frequencies ($\overline{w}_i^v = \frac{1}{k}\sum_l F_{il} 2.4419\left(10^{-9}\right) l^{3.346942}$, where k is the number of fish in the length-frequency sample).

Prior to escape-rings, only the probability of landing small fish affected the estimates, $\overline{w}_i^c$ and R_i ,

$$\overline{w}_i^c = \frac{\sum_l F_{il} w_l P_l^v}{\sum_l F_{il} P_l^v} \qquad R_i = \frac{\sum_l F_{il}\left(1-P_l^v\right)}{\sum_l F_{il} P_l^v} \quad .$$

With escape-rings both the probability of retention in the traps and the probability of landing small fish impacts the estimates $\overline{w}_i^c$ and R_i ,

$$\overline{w}_i^c = \frac{\sum_l F_{il} w_l P_l^r P_l^v}{\sum_l F_{il} P_l^r P_l^v} \qquad R_i = \frac{\sum_l F_{il}\left(1-P_l^v\right)P_l^r}{\sum_l F_{il} P_l^r P_l^v} \quad .$$

The probability that a fish of length *l* will be landed (rather than released) was estimated from observer data collected in 1992 and 1993 (Haist et al. 1999), and is shown in the figure below.

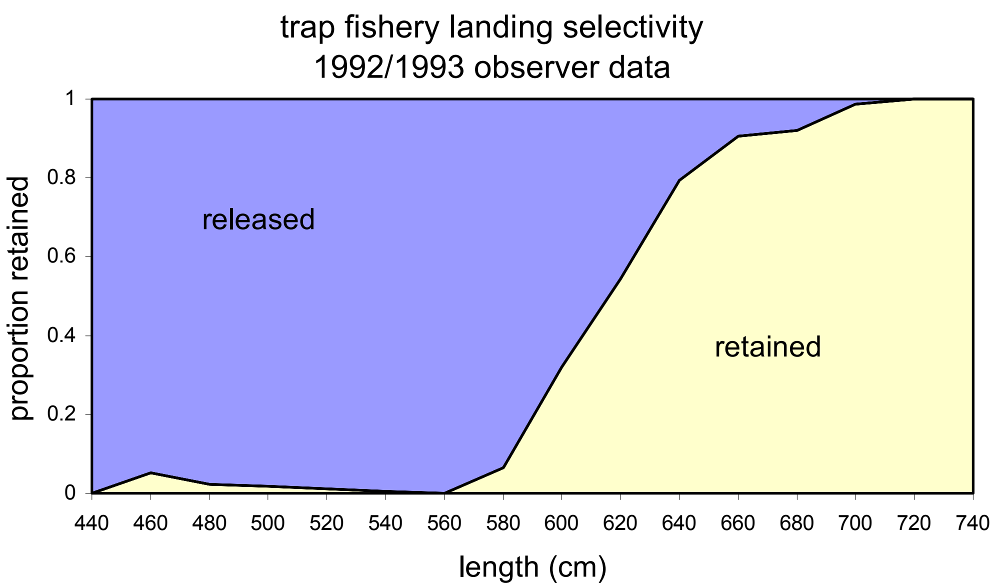


Table N.6 shows estimates of the parameters $\overline{w}_i^c$, $\overline{w}_i^v$ and R_i that were calculated based on the escape-ring retention selectivity function presented in this document and the landing selectivity function shown above.

Table N.6 Estimates of the parameters $\overline{w}_i^c$, $\overline{w}_i^v$ and R_i that were calculated based on the escape-ring retention selectivity function

Strata (250–450 fm)	$\overline{w}_i^v$	$\overline{w}_i^c$		R_i	
		no ring	3 7/8" ring	no ring	3 7/8" ring
Southern B.C.	2.68	3.63	3.89	1.02	0.32
Northern B.C.	3.27	4.00	4.22	0.50	0.16

The escape-ring selectivity function used is the 3-parameter model that includes the informative β^{90} prior. Results were virtually identical when the selectivity function with the uninformative prior was used.

For comparison, the values of $\overline{w}_i^c$ and R_i for the 3 7/8" escape-ring, that were obtained from the analysis of the 1997 escape-ring data are given in the following table.

Strata (250–450 fm)	$\overline{w}_i^c$	R_i
	3 7/8" ring	3 7/8" ring
Southern B.C.	3.85	0.52
Northern B.C.	4.22	0.25

The new escape-ring retention selectivity function, estimated from the 2001 study data, has little effect on the estimates of the mean weight of landed fish, $\overline{w}_i^c$. The effect on the ratio of the number of fish that are caught and released to the number of fish that are caught and landed is much larger. Overall, these revised parameter estimates will result in a 10-15% increase in estimated exploitation rates and a concomitant decrease in estimated vulnerable biomass, for the mark-recapture analysis over the period where escape-rings are operational.

Direct estimation of the number and size distribution of sablefish that are caught and the number and size distribution of those that are landed would be a much more accurate method to obtain these quantities. Inferring their values based on intermediate functional relationships (ie. the escape-ring retention selectivity function and the landing selectivity function) necessarily introduces uncertainty and potential error.

N.5 Literature Cited

Efron, B. 1982. The jackknife, the bootstrap, and other resampling plans. SIAM-CBMS: 38: 1-92.

Gagnon, P. 1992. The analysis of comparative trawl selectivity experiments. CAFSAC Working Paper 92/128. 17 p.

Gelman A., J.B. Carlin, H.S. Stern and D.B. Rubin. 1995. Bayesian Data Analysis. Chapman and Hall. London.

Haist, V., Hilborn, R., and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. Can. Sci. Advisory Res. Doc. 2001/135. 54 p.

Haist, V. and R. Hilborn. 2000. Sablefish stock assessment for 2000 and recommended yield options for 2001. Canadian Stock Assessment Secretariat Research Document 2000/157.

Haist, V., Hilborn, R., and M.W. Saunders. 1999. Sablefish stock assessment for 1999 and recommended yield options for 2000 and 2001. Can. Stock Assess. Sec. Res. Doc. 99/195.

Otter Research Limited. 2000. An introduction to AD model builder, version 4: For use in nonlinear modeling and statistics. Otter Research Limited. Sydney, B.C. Canada. 127 p.

Saunders, M. W., B. M. Leaman, V. Haist, R. Hilborn, and G.A. McFarlane. 1996. Sablefish stock assessment for 1996 and recommended yield options for 1997. PSARC Working Paper G96-5.

Saunders, M.W. and N. Surry. 1998. Preliminary results of blackcod escape ring study, F/V Ocean Pearl, November-December 1997. Report prepared for the Pacific Coast Blackcod Fisherman's Association.

Table A-1. Summary statistics for sablefish escape-ring study sets conducted in 2001.

					bottom depth (m)		Mean length (mm)			Sablefish/trap	
set	Stat area	Loc. code	Fishing ground	dur.	Begin	End	control	ring	diff.	control	ring
1	23	10	Barkley Canyon	43.5	444	271	654.1	678.5	24.4	6.4	4.0
19	26	8	N.Esperanza Canyon	37.0	412	567	637.3	670.8	33.5	2.0	1.2
20	26	8	N.Esperanza Canyon	37.8	578	508	593.3	630.8	37.5	7.4	2.0
43	11	10	South Scott Islands	28.0	622	624	684.1	703.9	19.9	4.5	4.2
44	11	7	South Triangle Island	48.3	348	583	667.4	690.3	22.9	8.6	5.3
55	08	14	Cape St. James	34.9	309	532	641.4	663.5	22.1	2.5	1.2
62	34	1	Flamingo Inlet	28.2	594	772	650.6	691.0	40.4	4.3	1.3
91	31	14	Rennell Sound	32.2	448	337	611.2	629.3	18.2	1.0	0.7
103	31	4	Tian Head	37.3	567	499	604.5	625.7	21.2	5.8	4.1

Table A-2. Summary statistics for the sablefish escape-ring study sets conducted in 1997. The "ring" results are from traps with 3 7/8 inch rings. Set 4 is not included because it had been rejected from the previous analysis.

				bottom depth (m)		Mean length (mm)			Sablefish/trap	
set	stratum	Fishing ground	dur.	Min.	Max.	control	ring	diff.	control	ring
1	I-48	Squally Channel	48.3	644	680	608.0	618.2	10.2	13.8	22.0
2	I-48	Squally Channel	47.0	514	536	540.3	575.5	35.2	36.7	18.0
3	I-24	Wright Sound	22.0	499	539	556.0	559.8	3.8	16.2	6.5
5	I-24	Whale Channel	24.2	499	574	582.7	605.4	22.7	7.1	6.6
6	I-24	Whale Channel	20.3	585	691	584.7	613.6	28.9	22.2	10.2
7	O-24	Kyuquot	24.6	459	539	661.2	670.7	9.5	9.8	10.9
8	O-48	Kyuquot	47.7	316	508	699.5	715.1	15.6	8.0	10.4
9	O-48	Crowther Canyon	42.8	289	629	665.7	687.0	21.3	13.6	8.5
10	O-48	Kyuquot	55.0	441	1134	619.4	651.4	32.0	10.5	10.7
11	O-24	Kyuquot	24.8	486	494	610.6	607.1	-3.5	10.1	8.9
12	O-24	Kyuquot	26.1	492	558	598.1	663.2	65.1	11.4	5.6

Erratum: Haist, V., A.R. Kronlund, and M.R. Wyeth. 2004. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: Stock Assessment for 2003 and Advice to Managers for 2004. Can. Sci. Adv. Sec. Res. Doc. 2004/055.

Dockside validation data used for the calculation of sablefish landings were misreported for the 2001 and 2002 calendar years. The discrepancy ranged from 3 to 11 percent depending on the calendar year and fishery gear type. In the case of the directed sablefish trap fishery, landings were under-reported by approximately 11 percent in 2001 and 8 percent in 2002. The impact of this shortfall was assessed by re-running the stock assessment model with the corrected landings data while leaving all other survey, logbook, and tagging data as published. Changes to probabilities in the decision table that represented advice to fishery managers were negligible as shown below:

Total Annual Catch 2004-2008	Expectation $P(B_{2009}>B_{2002})$		Expectation $E(B_{2009}/B_{2002})$	
	Original	Revised	Original	Revised
0	0.94	0.93	2.83	2.79
3000	0.91	0.89	2.57	2.55
4000	0.89	0.87	2.48	2.45
5000	0.87	0.85	2.37	2.35
6000	0.83	0.82	2.26	2.23

Updated landings statistics can be found in Haist et al. (2005).

References

Haist, V., A.R. Kronlund, and M.R. Wyeth. 2005. Sablefish (*Anoplopoma fimbria*) in British Columbia, Canada: Stock Assessment for 2004 and Advice to Managers for 2005. Can. Sci. Adv. Sec. Res. Doc. 2005/031.